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Du, Qiang

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INTEGRATED DECISION-MAKING IN THE CLADDING SUPPLY CHAIN

Qiang Du

A Thesis Submitted for the Degree of Doctor of Philosophy
University of Bath
Department of Architecture and Civil Engineering
May 2009

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Abstract

The cladding industry is relatively independent and complex, having contemporary features in a rapidly changing sector of the construction industry. The increasing complexity of the cladding procurement and fragmentation of the supply chain bring challenges for making informed decisions. The purpose of this research was to study the cladding design and procurement process, in particular the decision making process. It was hoped to develop an integrated decision making mechanism within the context of the cladding supply chain.

Based on preliminary exploration, a conceptual model of integrated communication and decision-making (ICDM) was proposed. Within this model, an Information and Communication (I&C) Hub acts as the pivotal platform of the information supply and communication in the supply chain and is managed by an industry level third party. It provides an effective and secure approach to information exchange and collaborative decision making.

A questionnaire survey was the key method of this research, while industry meetings and informal interviews were employed to provide in-depth understanding of the communication related issues in the industry. It was found that the participants of the cladding supply chain were experiencing difficulties of identifying information sources and accessing information, and that an industry level third party acting as an independent information source could be accepted by the cladding industry. Therefore, the I&C Hub gained its necessity and partial feasibility. It was also found that training opportunity for practitioners was limited and the usage of ICT had a large potential for improvement. A number of modifications on the I&C Hub and information flows within the ICDM were proposed to enhance its practicality, and the enhanced model was presented and evaluated by an industry meeting.

The conceptual model can only be completely validated by real cases; therefore, this study concluded with a recommendation for testing the framework in future pilot projects.

Keywords: *Cladding, Supply Chain, Procurement, Decision-making, Integration.*

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Lastly, and most importantly, I wish to thank my parents and wife for their love and encouragement. To them I dedicate this thesis.

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List of Abbreviations

AIA	The American Institute of Architecture
ARCOM	Association of Researchers in Construction Management
ASTM	American Society for Testing and Materials
B2B	Business to Business
BDB	Building down Barriers
BRE	Building Research Establishment
BS	British Standards
BSF	Building Schools for the Future
CAB	Council for Aluminium in Building
CAD	Computer-aided Design
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CIB	Conseil International du Bâtiment (International Council for Building)
CIBSE	Chartered Institution of Building Services Engineers
CICA	Confederation of International Contractors' Association
CIMclad	Computer-Integrated Manufacture of Cladding Systems
CIOB	Chartered Institute of Building
CIRIA	Construction Industry Research and Information Association
CladdISS	Standardised Strategy for Window and Cladding Interface
CLIP	Construction Lean Improvement Programme
CPD	Continuous Professional Development
CSCS	Construction Skills Certification Scheme
CWCT	Centre for Window and Cladding Technology
DCSF	Department for Children, Schools and Families
DGU	Double Glazed Unit
DH	Department of Health
DoE	Department of the Environment
DTI	Department of Trade and Industry
DETR	Department of the Environment, Transport, and the Regions
EPSRC	Engineering Physical Sciences Research Council
FMEA	Failure Mode and Effects Analysis
GANA	Glass Association of North America
GDP	Gross Domestic Product
GRC	Glassfibre Reinforced Cement
GRP	Glassfibre Reinforced Polyester
HMSO	Her Majesty's Stationery Office
HQ	Headquarters
ICBEST	International Conference on Building Envelope Systems and Technology
ICDM	Integrated Communication and Decision-making Model
I&C Hub	Information and Communication Hub
ICT	Information and Communication Technology

I/O	Input / Output
IOSH	Institution of Occupational Safety and Health
ISO	International Organization for Standardization
IT	Information Technology
JCT	Joint Contracts Tribunal
LAN	Local Area Network
LIFT	Local Investment Finance Trust
MoD	Ministry of Defence
N/A	Not applicable
NAO	National Audit Office
NEDO	National Economic Development Office
NHS	National Health Service
NPD	New Product Development
OECD	Organisation for Economic Co-operation and Development
PERL	Practical Extraction and Reporting Language
PfH	Partnerships for Health
PFI	Private Financial Initiative
PfS	Partnerships for Schools
PII	Partners in Innovation
PPP	Public Private Partnerships
PRN	Priority Risk Number
PTFE	Polytetrafluoroethylene
PUK	Partnerships UK
PVC	Polyvinyl Chloride
PVC-U	Unplasticised Polyvinyl Chloride
PVDF	Polyvinylidene Fluoride
QA	Quality assurance
RIBA	Royal Institute of British Architects
R&D	Research and Development
SCI	Science Citation Index
SCM	Supply Chain Management
SFE	Society of Facade Engineers
SPSS	Statistical Package for the Social Sciences
SQL	Structured Query Language
TNs	Technical Notes
TQM	Total Quality Management

Chapter 1 Introduction

1.1 Introduction

This research has studied ways to improve the cladding supply chain. The cladding supply chain comprises all the participants who are involved in cladding procurement, including clients, architects, engineers, consultants, main contractors, cladding specialist contractors, suppliers, and manufactures. With the increasing complexities in cladding materials and techniques, the supply chain becomes deep. There are challenges to make informed decisions by the appropriate parties at the right levels.

1.2 Aim of the research

The aim of this research project is to study the cladding design and procurement process, in particular the decision making process. It was hoped to develop an integrated decision making mechanism within the context of the cladding supply chain.

1.3 Objectives

There were several objectives for the research. The objectives in the order of importance were as follows:

1. Review and establish the background of the present procurement strategies, supply chain

management and other management expertise within the construction industry via current literature and participation in industry workshops/conferences.

2. Review and identify the main problems and trends that occur in the cladding sector;
3. Explore and develop the mechanism of integrated decision making in the cladding sector;
4. Validate and disseminate the research findings.

1.4 Scope of the research

The research originated from, and took forward, a DTI PII project (No. 39/03/635) 'Communication down the Cladding Supply Chain', which was completed by Ledbetter (2004a). In that research, supply chain management was emphasised in the cladding sector, and communication was identified as a key factor to successful procurement.

Decision making in the cladding supply chain requires both technical knowledge and information but also appropriate strategies for management and the exchange of information. This thesis considers:

- A technical knowledge bank and repositories;
- Management processes and the parties involved.

1.5 Justification for the research

Identification of the research problem and the justification for the research is made on three counts:

- Industrial significance
- Current knowledge
- Ability to apply findings

Firstly, the motive of the research lies in the significance of decision making to the problematic construction industry and cladding sector. Many procurement initiatives, such as Prime Contracting and Private Finance Initiative (PFI), have been employed in the public sector, but they also generate some new and serious issues. What is needed is a generic solution with contemporary and proven technology and management expertise, such as the combination of information technology and supply chain management.

Secondly, grounds for the research originate from the lack of published literature addressing the issues, concepts and problems of decision making and supply chain management in the cladding sector. Even for the wider generic construction industry, supply chain management is a relatively new topic. Most supply chain references concern supply chains in automotive, aerospace, retailing and other manufacturing industries.

Finally, if a framework for knowledge and the exchange of project information can be developed to aid decision making then, the processes of procurement and performance through whole-life cycle would be secured, and all participants' interests could be achieved in an agreeable manner. Only then can 'real' long-time partnering relationships be successful.

1.6 Structure of the thesis

The thesis is organised as follows. Chapter one introduces the thesis. The aim and objectives that give rise to the research are posed and considered. Justification for the study is discussed.

The chapter also gives a brief description of the origin and scope of this thesis.

Chapter two provides the background of the research. In particular, this chapter describes the development of the cladding industry and emphasises the increasing complexity of the materials, solutions and supply chains, which make the collaborative decision making necessary but also very challenging.

Chapter three reviews the published literature that helps determine the research objectives. The review further emphasises the need for the research due to the insufficient literature published on the subject.

Chapter four states the methodology employed during the research and provides a discussion of the research methodology, the adoption of research tools, the process of collecting data and strategies used to analyse the data. The data collection mainly uses a questionnaire circulated in the cladding industry, while interviews and industry meetings are employed prior to the questionnaire survey to discover the realities of the industry. Concerns in ethical issues, reliability and validity are also discussed.

Chapter five describes the preliminary exploration and proposes a conceptual model of integrated communication and decision-making (ICDM). The exploration starts by programming on-line software to investigate the feasibility of using a project-based IT platform in the communication and decision-making process within the cladding sector. At the same time, a further investigation into the automotive industry that is perceived to perform better is carried out to gain further experience and transfer lessons learnt there. It is found that an industry level third party may act as a ‘hub’ to facilitate information supply and communication. Therefore, a conceptual idea of the Integrated Communication and Decision-making Model (ICDM), centring around an Information and Communication Hub (I&C Hub), is proposed. This conceptual model is the base for continuing the research and a survey is used to test the concept.

Chapter six presents analysis of the industry survey and research results. The findings of the research are further used for examining and modifying the concept of an ICDM.

Chapter seven proposes a number of modifications on the I&C hub and information flows within the ICDM to enhance its practicality. The enhanced model is presented and evaluated by an industry meeting.

Chapter eight concludes the thesis, highlighting the contributions, implications and limitations of the research. A cluster of future work is recommended.

Chapter 2 Background

2.1 Introduction

Chapter 1 introduced the research illustrating the aim, objectives, scope and justification. In this chapter, a background to the development of the cladding industry and its current form is given. The author has benefited from studying for an MSc in Facade Engineering at Bath University, several years involvement with the Centre for Window and Cladding Technology (CWCT) and a number of industrial contacts. The knowledge and understanding gained is employed in setting this research in the context of the cladding industry.

2.2 Definitions and explanations

Cladding

Cladding is the covering of one material with another, but has several different definitions in various contexts. Regarding building construction, one of the well accepted definitions is given by the Penguin Dictionary of Building (MacLean and Scott, 1993) as "(1) A weather-tight skin covering an external wall, as part of the building enclosure. It is usually functional, but can include decorative facade cladding, and may have insulation or give some degree of security. Cladding is non-loadbearing and has to bear wind loads, impact damage, and temperature extremes. Long panels must allow free thermal movement. It can be of any durable material, such as profiled sheeting, brickwork, or weatherboard, or a system such as curtain walling, patent glazing, cladding panels, insulating over-cladding, or thin stone facings. Doors and windows maybe included, but solid masonry is not cladding. (2) A finishing or protective shell".

The only possible flaw in this comprehensive explanation could be the 'non-loadbearing' aspect. A broader definition of a building envelope may include loadbearing forms of building enclosure. There is a broad spectrum of non-loadbearing cladding ranging from very lightweight to heavyweight. If follow that there is a crossover between loadbearing and non-loadbearing envelope. There are many forms of cladding and Ledbetter (2004b) attempts to catalogue this is “a taxonomy of facades”.

A better accepted definition of cladding is given by CWCT (2000a), “Cladding is an all-encompassing term for the external skin of a building which keeps out the weather and provides the building’s aesthetic effect. In low-rise construction it may support its own weight but self-weight and wind loading are normally transferred to the structural building frame. It may form the full thickness of the vertical envelope of the building but can simply be the outer layer with additional layers providing insulation and the internal lining.”

Nevertheless, to ignore loadbearing cladding would be to ignore the fact that both loadbearing and non-loadbearing envelope construction may be used adjunctive to one another on a building and be supplied by parallel supply chains.

For simplicity, the focus of this research is to study the supply of modern non-loadbearing envelope. Of course, many of the findings will be transferable to loadbearing envelopes.

Supply chain

All industries are formed around supply chains. There are common features across different industries but also marked differences. A good definition is give by Sahin and Robinson (2002) as “A supply chain consists of supplier/vendors, manufacturers, distributors, and retailers interconnected by transportation, information and financial infrastructure. The supply chain’s objective is to provide value to the end consumer in terms of products and services, and for each channel participant to garner a profit in doing so.”

The application of the supply chain concept to construction has been recognised as a management strategy to improve the performance of the industry (McGeorge and Palmer, 2002). It has found favour particularly with the research community and various government policy making units worldwide. The application of supply chain management has had mixed usage among construction industry practitioners. However, these appear to be ad hoc examples of industry participants engaging in various forms of supply chain management behaviour, particularly in developing more long-term strategic relationships.

Cladding supply chain

Cladding supply chain is clarified by Ledbetter (2004a) as a ‘network’. In this thesis, cladding supply chains comprise the participants involved and flows between the participants. The participants include clients, consultants, design team, main contractors, cladding sub-contractors, suppliers and so on. The flows include information flow, financial flow, production and services flow, and some hidden flows such as value flow.

The application of supply chain management in the cladding sector could be found in recent research, (Pavitt, Gibb and Sutherland 2001, Pavitt 2002, Pavitt and Gibb 2003a, 2003b) and ‘Computer-Integrated Manufacture of Cladding Systems (CIMclad)’ project (Agbasi et al. 2001a, 2001b, 2004, Kalian et al. 2001). Supply chain management in this thesis is a systematic tool which provides the analysis, context and essential elements, rather than the research target.

2.3 The development of cladding industry

Brookes (1983) declares the most dominant characteristics of cladding and cladding systems are frame and prefabrication. The use of frame construction provides two main revolutionary advantages. Firstly, more square footage of usable floor area can be gained compared with masonry construction. This amounts to about 10 percent in a medium size building. Secondly, by reducing the self-weight of the skin, the whole weight of the building is reduced and therefore may be carried on a lighter structured frame. The load on the foundations may be lessened and taller buildings may be constructed.

The first building with a skeleton of wrought iron, the Menier chocolate factory, was built near Paris in 1871-1872. Its external skin acts purely as a non-loadbearing panel infill. In the late 19th century, steel frame building achieved a dominant position in Chicago (Brookes, 1983).

In terms of prefabrication, a portable colonial cottage was recognised an early example by using a timber frame with interchangeable timber panels in 1833 (Herbert, 1978). However, the most famous example in the 19th century was the Crystal Palace built for the London Exhibition of 1851. In the twentieth century, prefabrication developed rapidly with the employment of new techniques and materials. "Profiled metal, cast iron, and precast concrete emerged as new systems of building with an enormous potential for prefabrication" (Brookes, 1983).

In the 1980s, a number of cladding types have been developed and used in buildings and they were mainly grouped as follows (Brookes, 1983):

- Precast concrete cladding
- Glass reinforced polyester (GRP)
- Glass fibre reinforced cement (GRC)
- Profiled metal and asbestos cement cladding
- Sheet metal cladding panels
- Curtain walling
- Masonry
- Others

150 years after the Crystal Palace, there have been a wide variety of materials and methods used to realize novel appearance and high performance on building façades. This leads to complexity, particularly architectural design with many types of cladding on a single building, and to many specialisms in the cladding sector.

Ledbetter (2001a) explains the specialisation well. Before the Victorian era, he notes, the architect was ‘the master builder’, designing buildings for construction by a contractor. Thereafter:

“*The advent of framed buildings in the late 19th century gave rise to the role of the structural engineer. The introduction of mechanical ventilation and air conditioning in the middle of the 20th century gave rise to the role of the building services engineer. By the end of the 20th century, high performance facades had become so complex that facade engineering began to emerge as a specialism.*”

However, the industry should not retreat from complexity as it defines the aesthetic of the building whilst meeting the ever increasing demands of performance specification. The wide variety of solutions and the depth of knowledge required have led to specialisation by contractors and the growth of a specialised construction industry. Specialisation is a powerful driver for cladding innovation, but at the same time, more participants with their own interests create a cladding supply chain that becomes ever more complex.

2.4 Decision-making in the cladding supply chain

The cladding industry is currently relatively independent and complex, having contemporary features in a rapidly changing sector of the construction industry. The increasing complexity of technology and materials of building envelopes leads to continuously deepening specialisation in this sector, where more participants are involved and thus a multi-tier hierarchy of the cladding supply chain is formed.

Studying the supply chain in detail, which is described by Ledbetter (2004a) as a supply net, the participants can be seen as processors linked by different procurement processes, and it is found that the relationships between players are complicated and are often fragmented. At the same time, the intertwining streams of information flow, product flow, service delivery and payment, frequently cause misunderstandings and conflicts among the participants in the network (Du, 2007).

Decision making is the cognition process leading to the selection of a single course of action from the many available. The decision to choose and produce an appropriate ‘wall’ sounds not too difficult if compared with manufacturing a conceptual car; however, the reality of high failure rate in windows and cladding for many and various reasons tells a different story, though some better technical solutions and managerial initiatives have emerged.

In fact, many interrelated factors, including tightening regulations, have to be considered to keep a reasonable ‘balance’ on facade design. At the same time, performance based specification has become a global trend, which means all people involved in the cladding procurement process could play a role in design and decision making to some extent. However, the knowledge gap of the decision makers is widening in a rapidly changing world.

The scene looks very chaotic – people with different interests, flows of information with uncertain routes along duplicate paths, important aspects of performance with conflicting requirements, and increasing knowledge that does not reach the relevant decision makers – all of these are present in a relatively small and very interconnected industry.

Therefore, making informed decisions at the appropriate levels of the supply chain in the processes of procuring cladding is very important but challenging work indeed.

Chapter 3 Literature Review

3.1 Introduction

Chapter 1 introduced the research explaining the aims, objectives, scope and justification. Chapter 2 briefly illustrated the development of the cladding industry. This chapter reviews published literature that provides the progress of related research and background for this research.

The limited academic literature in this area forced the author to apply a wider resource, including government reports, technical notes and associated organisations' websites. The author made great effort to ensure the sources were objective and accurate, before they were used to establish the whole picture of the cladding industry and background to decision making.

The key words adopted in the literature search included: cladding, construction management, decision making, supply chain, communication, interface management, knowledge management, procurement, innovation, information technology.

To make a logical sequence, the search results are combined into the following eight main headings;

- Understanding cladding and building facades
- Cladding procurement
- Recent research on cladding
- Construction management concepts and initiatives
- Communication and knowledge management in construction
- IT in construction
- References from the automotive industry
- Decision making

The first three headings emphasise the development of ‘cladding’, and are illustrated in sections 3.2 to 3.4; the following three sections are a discussion of the broader background, of where the cladding industry exists and significant management concepts and implementations that can be found. Then the development concerning supply chain management in the automotive industry is reviewed. Finally, recent developments of decision-making theories will be stated from a social science perspective.

After the topics above have been reviewed, a summary is given to clarify the whole basis from which this research was carried forward.

3.2 Understanding cladding with facades

3.2.1 Basic understandings

The different definitions of ‘cladding’ were compared and explained in section 2.2. In this research, cladding cannot be separated from the building facade.

Facade within the context of building is “a front wall with formal decoration or any outside wall with high-class cladding” (MacLean and Scott, 1993). ‘Formal decoration’ and ‘high-class cladding’ may suggest the exclusion of traditional plain blockwork walls and some concrete panels which are loadbearing.

Another relatively general definition of facade comes from Oxford Concise English Dictionary (1990), “1) the face of a building, esp. its principal front; 2) an outward appearance or front, esp. a deceptive one”.

From a facade professional's perspective, "the facade could be vividly seen as a meeting point between the indoor and outdoor world. It connects the environments – physically, visually and acoustically – and allows us to extend the building spaces in response to user demand" (Hall, 2004).

Technically speaking, without emotion, it could be simply understood as the location of the cladding and what the cladding supply chain delivers as components and assemblies. However, during the process of design and construction, the cladding of a building needs to be treated as an organic part to form the systematic skin rather than individual panels. Unless it is designed holistically, it will fail to deliver performance at a whole building level.

Therefore, the types of facades and components are described from an integral view in the following sections.

3.2.2 Types of facades

A classification system is the basis for research and knowledge management.

In the 1980's, the different types of building facades were summarised by the following factors (Brookes, 1983):

- Building application
- Material type
- Form of construction
- Support type

However, with the rapid changes, this classification is not sufficient for today's cladding. On the other hand, without an appropriate classification, walls are often described simply as curtain walls and an inappropriate specification is used. In the UK, curtain walling standards are frequently wrongly applied to ventilated rainscreen walls. In Europe, there is a standard for curtain walling but no standard for rainscreen walls. The reason for the confusion on terminology could be the evolutionary development of construction forms (Ledbetter, 2004b). These issues have seriously puzzled participants in this sector and affect both design and construction activities.

Ledbetter (2004b) provided several primary factors which should be considered to classify the cladding:

- Construction method
- Materials
- Method of sealing against water ingress
- Ventilation and hygrometric performance
- Structural system

Based on these principles, a systematic classification would facilitate the selection of appropriate solutions, understanding of the detailing requirements and continuous solution improvement. Among these considerations, the construction method and materials are the two most frequently mentioned classification means in practice.

By Construction method

According to the type of construction, cladding could be grouped initially to loadbearing walls and non-loadbearing curtain walls.

Loadberaing walls may be blockwork walls or concrete panels. Non-traditional forms of loadbearing construction include blockwork walls covered by an outer rainscreen, and pre-cast concrete panels or in-situ concrete walls.

Curtain walling is a form of vertical building enclosure which supports no structural load other than its own weight that of ancillary components and the direct forces, including windload, snow and ice load, access loads, applied loads and accidental impact loads, which act upon it. Although the term is sometimes restricted to metal framed curtain walls, the above definition embraces many different construction methods and materials including non-loadbearing precast concrete (CWCT 1997, CWCT 2000b, CEN 2003). Curtain walling includes a wide range of wall types as follows (Ledbetter 2004b, CWCT 2001):

Stick system curtain walling comprises a group of horizontal and vertical sticks to form a lightweight grid, where panels or glazing are infilled, Figure 3.1. The joints in this system are good at accommodating variable geometries and movement, so it is very flexible and versatile and suitable for irregular shaped facades. The transoms and mullions are often extruded aluminium protected by anodising or powder coating in most cases, cold-rolled steel for better fire resistance performance, or aluminium clad with PVC-U (Ledbetter 2004b, CWCT 2001).

Unitised Curtain walling comprises storey-height, pre-assembled units of a steel or aluminium framework with glazing and infill panels, Figure 3.2. The dimensions of the units are usually based on glazing dimensions or other repeat features of the facade. Compared with stick systems, the fewer site-sealed joints of unitised systems require less site installation work and their use generally leads to a reduction in air and water leakage, though transport and on-site storage facilities will be extra considerations (Ledbetter 2004b, CWCT 2001).

Panellised curtain walling comprises large prefabricated panels of bay width and storey height, Figure 3.3. Panels may be precast concrete or comprise a significant structural steel framework to support cladding materials. Panelised systems are supported by primary structure columns directly or by the floor slabs close to the columns. Compared with unitised construction, it allows better control of quality and rapid installation with the minimum number of site-sealed joints, but the costs and technical pressure on manufacture, handling, storage, transport and erection make it less common (Ledbetter 2004b, CWCT 2001).

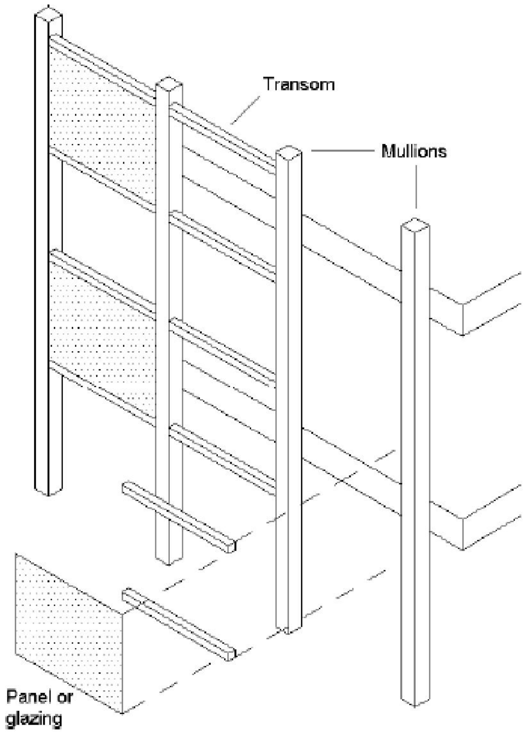


Figure 3.1 Stick system curtain walling (CWCT, 2001)

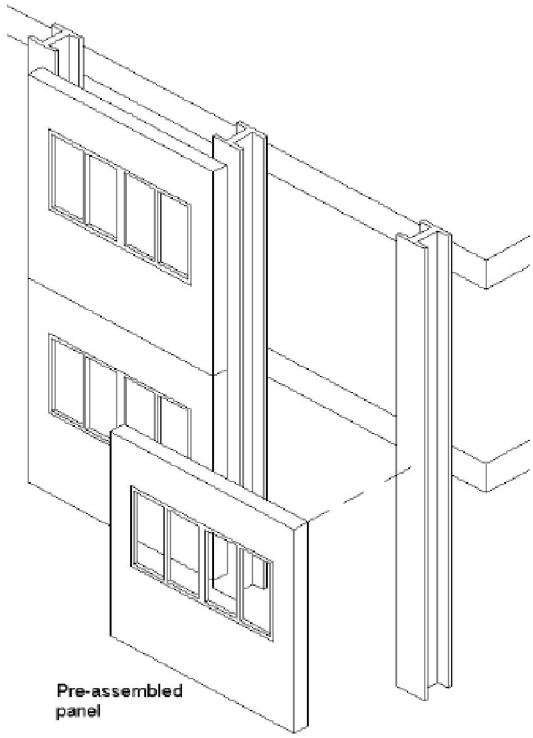


Figure 3.3 Panellised curtain walling (CWCT, 2001)

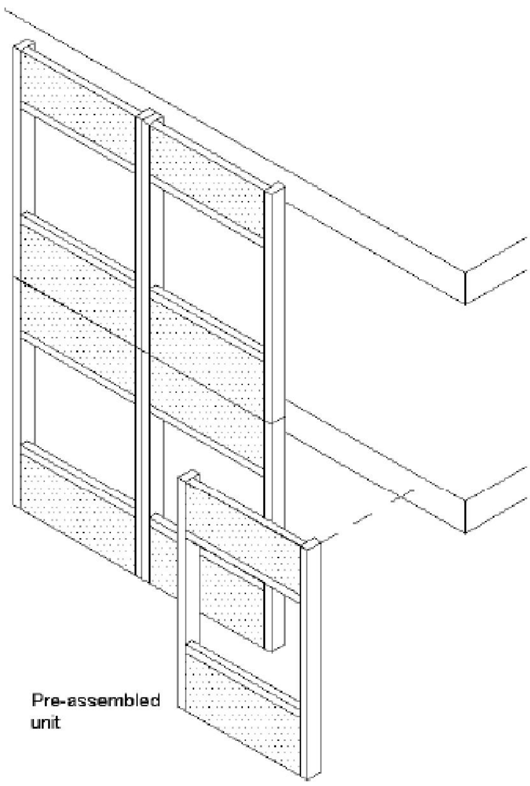


Figure 3.2 Unitised curtain walling (CWCT, 2001)

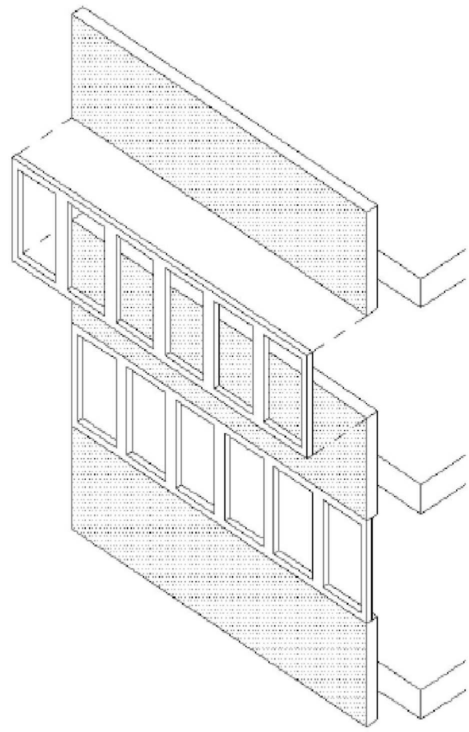


Figure 3.4 Spandrel panel ribbon glazing (CWCT, 2001)

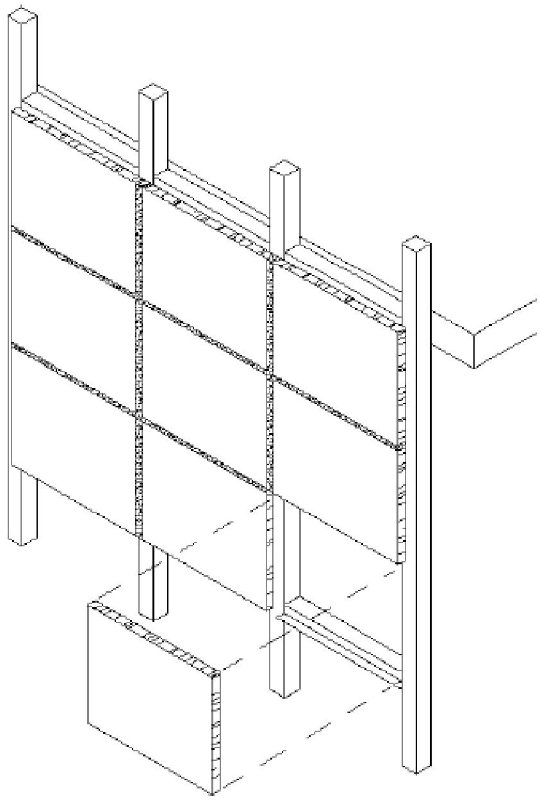


Figure 3.5 Structural sealant glazing (CWCT, 2001)

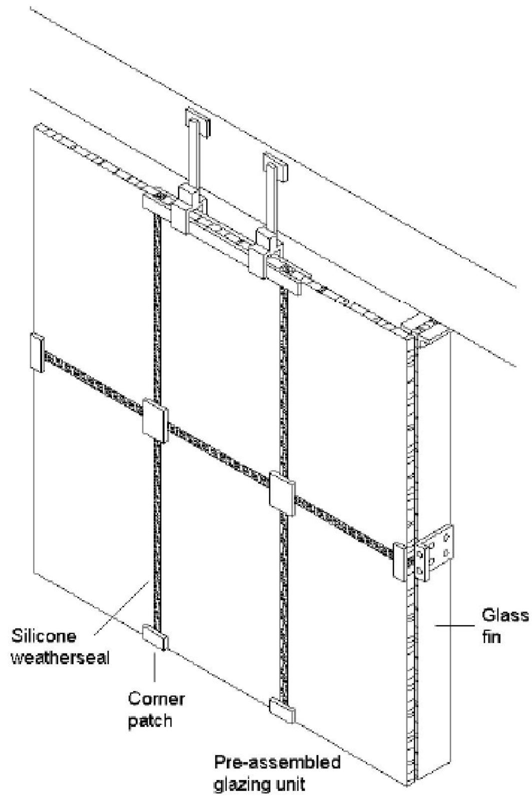


Figure 3.7 Structural glazing – suspended assembly (CWCT, 2001)

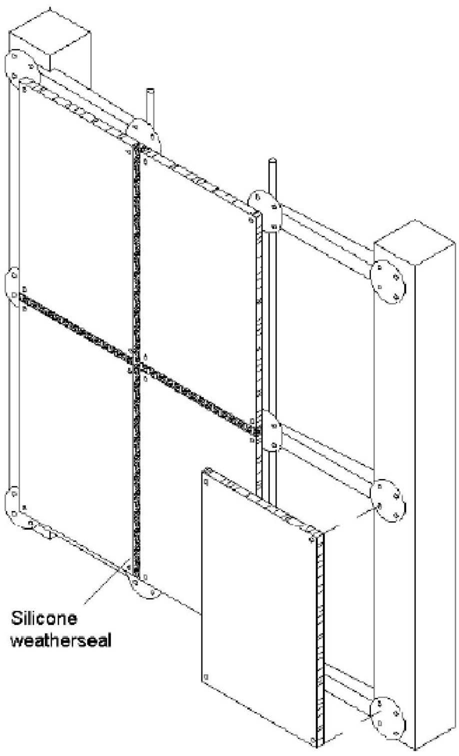


Figure 3.6 Structural glazing – bolted assembly (CWCT, 2001)

Spandrel construction comprises horizontal spandrel panels supported from the vertical columns or the floor slabs, and ribbon glazing fixed in to form a strip appearance, Figure 3.4. Spandrel panels are often prefabricated or precast concrete units (Ledbetter 2004b, CWCT 2001).

In addition, **structural sealant glazing** and **structural glazing** have been more and more popular in prestige buildings. Structural silicone can be applied to the previously described curtain walling types to achieve a building exterior that is free from protrusions (Figure 3.5). Structural glazing may be in the forms of bolted assembly (Figure 3.6) or suspended assembly (Figure 3.7). They also come under the definition of curtain walling (Ledbetter 2004b, CWCT 2001).

Choice of curtain wall type requires a comprehensive decision-making process. The dominant factors are cost, appearance, time scale, and access (CWCT, 2000b). Another critical consideration is health and safety. The greater the pre-assembly proportion, the lower the health and safety risk we will experience (Gibb et al., 2004).

By Materials

A classification of cladding materials has been proposed by Harris and Keiller (1999) as follows:

- Metals
- Timber
- Glass and ceramic
- Cement, concrete and terracotta
- Stone
- Finishes
- Rubber and plastic
- Sealants and adhesives
- Bitumen
- Fabrics

What needs to be emphasised here is that the classification is very broad. Every material above has a considerable number of sub-groups, and each from them has its own properties in different aspects. According to client's requirements and relevant conditions, a decision has to be made by appropriate people who have sufficient knowledge, and it is never straightforward. This is further complicated because new or derived materials emerge rapidly and frequently.

Others means of classification

Apart from construction method and materials, there are some other means to categorise building cladding, such as method of envelope sealing, ventilation and hygrometric considerations, and structural system (Ledbetter, 2004b).

Envelope is sealed in a number of ways against air and water ingress. The fundamental principle is to consider the air leakage control and water penetration as separate functions. According to this, the façade may be categorised as follows (Ledbetter 2004b):

- Face sealed construction
- Drained construction
- Drained and ventilated construction
- Pressure moderated cosntruction

Summary

The cladding industry is rapidly developing, which means new construction methods, materials and structural solutions will emerge continuously. Therefore, an appropriate and comprehensively considered classification of facades will facilitate design, evaluation, construction and even innovation in a building project. On the other hand, the classification could also evolve due to the impact of innovation.

From the angle of social science, an accurate definition and taxonomy are critical for decision making. During the process of long-term decision making, redefinition and reclassification happen frequently after analysing a recent development and lead to optimised decisions.

3.2.3 The ancillary components

Apart from the main components of curtain walling, such as panels, transoms and mullions, the ancillary components are also crucial for the performance of the facade as a whole. Here, brackets, sealants, gaskets and finishes are emphasised but there are many more components and additional items.

Brackets

As the link between the curtain wall and the structure brackets, normally designed by the system fabricator, are vitally important to the buildability, safety and seviceablility of the whole system. The main functions of brackets are the following (CWCT 2000c, SCI 1992):

- Transfer loads;
- Accommodate induced deviations (CWCT 2000g, BS 5606 1990);
- Accommodate inherent deviations;
- Resist corrosion (CWCT 2000h, BS5493 1977, CWCT 1996, BS EN ISO 12944 1998);
- Resist fire (HMSO, 1992);
- Buildability. It should be quick and simple to fix, adjust, inspect and maintain.

Bespoke connections could account for around 20 percent of the cost of a curtain walling system, the same proportion as the framing members themselves. Design of the interface between the frame and cladding must be appreciated and discussed between the structural engineer, architect and cladding contractor at an early stage for it to be effective (CWCT, 2000c).

Gaskets

Gaskets are widely used to seal joints in the building envelop mainly to limit the passage of water and air. The additional functions of a gasket might be to retain one component within another, transmit forces across the joint, enable positional adjustments to be made to overcome induced deviations, and allow relative movement of the joint surfaces. Gaskets could be categorised according to seal types, fixing methods, materials, and so on. Insufficient knowledge on different properties of different types could result in poor design, installation and durability, and further severely affect the performance, especially watertightness, which will be expensive to put right. (CWCT 1996, CWCT 2000d, BS3734 1997, BS 4255 1986, BS 6903 1993, Harris 1996).

Sealant

A sealant is principally used to seal the joint against water ingress and sometimes air leakage within a cladding and window system. It is required to be adhesive to the substrate materials without damage, able to deform to accommodate movement of the joint, weather resistant and durable. To meet the requirements, an appropriate generic type and formulation of sealant must be selected, the sealant joint must be properly designed, constructed and prepared, and the sealant must be correctly mixed, installed, and tooled. Backing strip may be used to help achieve the correct depth of sealant and a joint filler to help form the joint prior to seal installation. A wide range of sealant types with various properties are available, such as Acrylic resin, polysulfide, polyurethane and silicone sealants. The knowledge of substrate materials and the expected movement of the joint are also critical for sealant selection. (CWCT 2000e, BS 6093 1993, BS 6213 1982, CIRIA 1997).

Finishes for metal

To protect metal components against corrosion or for aesthetic effects, finishes may be required. In building façades, finishes are mostly applied to aluminium and carbon steel rather than other metals. Before the 1990s, the choice of finishes was limited to silicone-modified polyesters (SMP) and fluorocarbon (PVF^2), stainless steel and anodising (Brookes and Grech, 1990). Currently, there are so many types of finishes available but they can be roughly divided by whether they are organic or inorganic.

Inorganic finishes mainly include zinc coating, vitreous enamel and anodised film. The primary protection for most carbon steel is zinc coating, which will be sufficient for internal components and external elements with design life less than 30 years. In fact, zinc coatings will corrode as well though at a much slower rate than the steel (CWCT, 2000f). Vitreous enamel, a borosilicate glass, can produce a hard durable and abrasion resistant surface with a life expectancy in excess of 50 years for cladding panels although it is brittle to a degree (CWCT, 2000f). Anodised film, a dense, hard and durable oxide layer on the surface of aluminium, can be produced by the anodising process. An anodic film is integral with the metal (rather than a coating applied onto its surface) and therefore immune to loss of adhesion, and its expected life will be more than 50 years. (BS 3987 1991, CWCT 1996).

Organic coatings, which may be applied in liquid or powder form, can prevent oxygen, water and aggressive chemicals contacting the metal surface. The predominant organic finish for windows and curtain walling is polyester powder coating partly because of its toughness, abrasion resistance performance and the widest range of colours availability. However many types of wet-applied finishes are currently used for cladding panels, such as Polyvinylidene Fluoride (PVDF), Poly-vinyl-Chloride (PVC), alkyd amino, polyester. They have various properties and service life from 10 to 30 years (AFA 1999, BS 4842 1994, BS 6496 1984, BS 6497 1984).

3.2.4 Summary

This section illustrates the complexity of cladding from the technical angle. The rapid development within and outside the cladding industry contributes to the trend of increasing complexity, which has an irreversible momentum. When the complexity can not be managed by a single party with limited knowledge and skills, deeper specialisation is required. New professionals emerge to help. This growth in the number of specialisms leads to complexity of communication.

In the next section, the cladding procurement process will be stated from a managerial perspective to show the different participants and different approaches to procurement.

3.3 Cladding procurement

3.3.1 Considerations on cladding procurement

A complex picture of a building facade has been drawn in the last section; however, the real handicap is how it could be delivered. To procure a wall, a number of principal considerations need to be applied (CWCT, 2001):

- Performance
- Appearance
- Cost
- Materials
- Quality

The scope of the considerations is extraordinarily wide, especially for materials, performance and costs, Figure 3.8.

Cost	Materials	Performance	Quality	Appearance
Capital costs	Metals	Water resistance	Various systems	Diverse views
Whole life costs	Plastics	Air permeability		
Warranties	Glass/glazing	Windloading		
… …	Stones	Thermal		
	Timber	Fire		
	Fabrics	Moisture		
	Ceramics	Acoustics		
	Insulation	Movement		
	Gaskets	Safety		
	Sealants	Lodads		
	Finishes	Daylight		
	… …	Maintenance		

Figure 3.8 Cladding procurement considerations (adapted from CWCT 2001)

Cost

Cladding has a wide range of costs, from £100/m^2 to over £1500/m^2 in 2000, (CWCT, 2001). The cost of a facade related not only to the technical performance but also the materials used and the image created. Expensive facade can often be achieved by using high-profile materials and spectacular designs. In general, the client wants the best cladding he can procure within his budget. Also, the whole life-cycle costs should be considered from the beginning (Bamforth, 2003), which will affect the capital costs invested.

Materials

The materials used in cladding and fenestration can be broadly classified, as described in section 3.2; however, to meet diverse design and cost requirements, each material type may include many forms and solutions to be employed. Taking a further example of glass, a great variety of separate materials or solutions have been adopted, Figure 3.9.

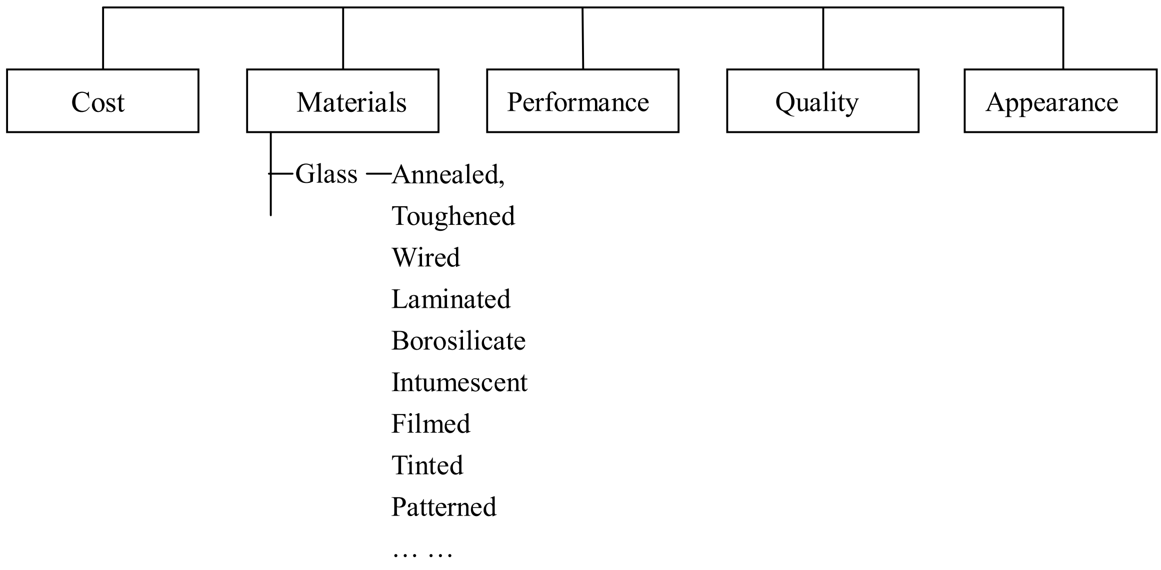


Figure 3.9 Glass procurement considerations (adapted from CWCT, 2001)

The level of complexity means that decisions about material performance have to be taken by specialists or with their assistance (CWCT, 2001). All too frequently the architect or engineer does not fully understand the full implications of selecting particular products or materials, so manufacturers or consultants often need to be involved at an early stage to provid relevant advice. Some larger architectural and engineering practices have established in-house teams of building facade specialists.

Performance

Building envelopes are required to provide a broad based performance spanning over many aspects of building use (Keiller et al., 2003). However, each of these is quite complex, and at the same time, the performance requirements may conflict one with another. Take an example of glass selection, a range of balanced performance factors have to be considered carefully, as summarized by *Guidance on Glazing at Height* (Keiller et al., 2005), Figure 3.10. These make the design a very cautious process and need collaboration between different parties. The role of facade consultants is increasingly important because they can draw relevant information from various sources including manufacturers and take an overview of the building cladding performance (CWCT, 2001).

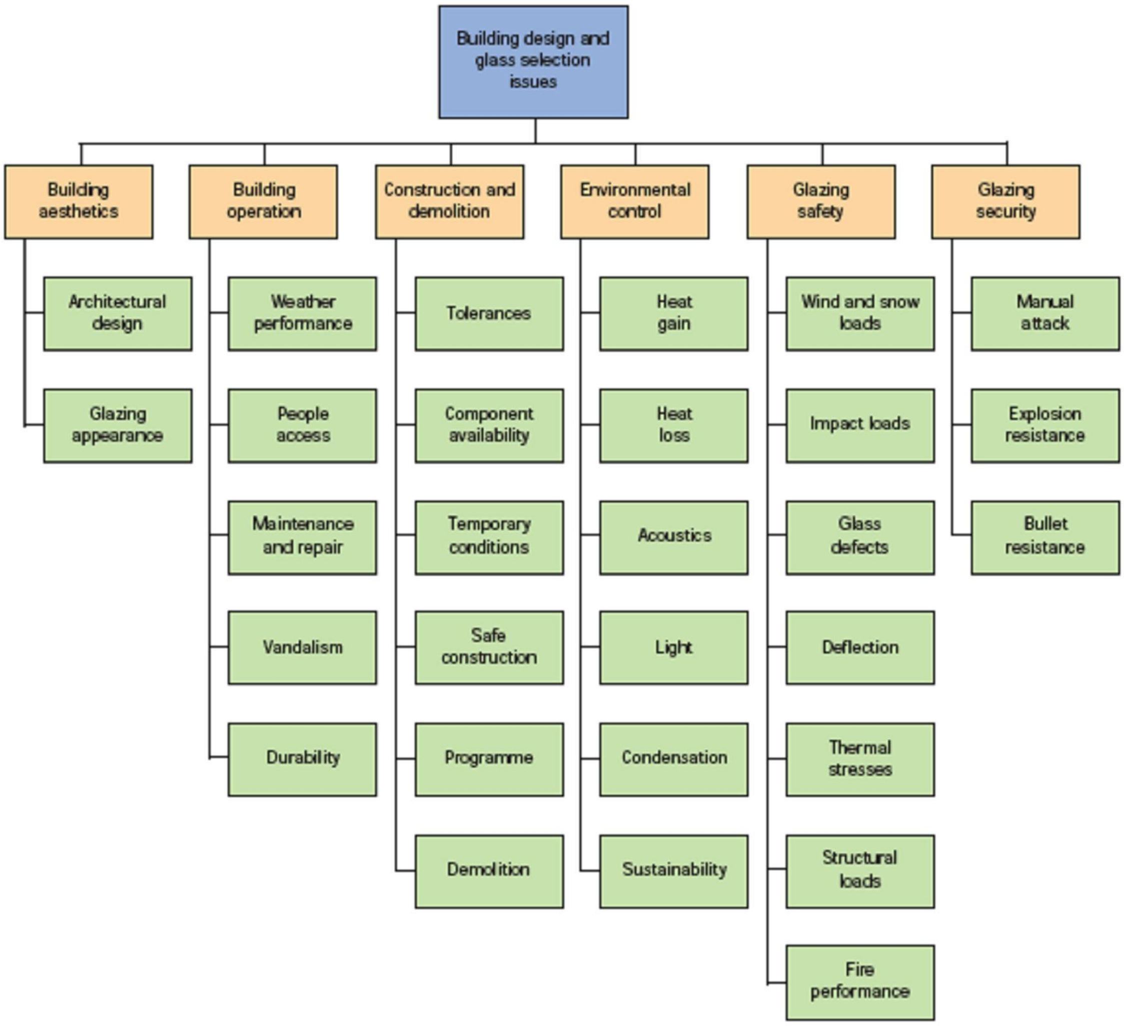


Figure 3.10 Considerations on glass performance specification (Keiller et al., 2005)

3.3.2 Procurement routes

The reasons that the design, manufacture and installation of building cladding are complex has been summarised by Ledbetter (2002):

- The diversity of materials is high,
- The number of products is large,
- The performance requirements;
  - differ from contract to contract,

  - are numerous and interactive,
  - may conflict with one another.

For this reason the supply chain involves many participants, many contractual interfaces and many causes for misunderstanding and conflict, which further lead to complex supply chains. There are currently several generic procurement forms in the construction industry (CWCT, 2001):

- Traditional contracting
- Construction management
- Management contracting
- Design and Build
- Partnering

3.3.3 Cladding supply chain

Cladding supply chain is clarified by Ledbetter (2004a) as a ‘network’. In this thesis, cladding supply chain comprises of the participants involved and flows between the participants. The participants include clients, consultants, design team, main contractors, cladding sub-contractors, suppliers and so on. The flows include information flow, financial flow, production and services flow, and some hidden flows such as value flow (Agbasi et al., 2001).

The application of supply chain management in the cladding sector could be found in recent research, such as ‘A Standardised Strategy for Window and Cladding Interface (CladdISS)’ project (Pavitt, Gibb and Sutherland 2001, Pavitt 2002, Pavitt and Gibb 2003a, 2003b) and ‘Computer-Integrated Manufacture of Cladding Systems (CIMclad)’ (Agbasi et al. 2001a, 2001b, 2004, Kalian et al. 2001). Supply chain management in this thesis is considered to be a systematic tool which provides the analysis, context and essential elements, rather than a research target.

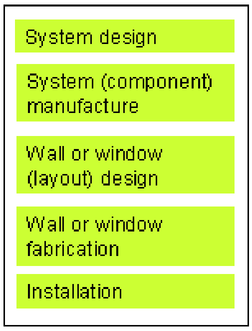
In the cladding industry, the work of design, manufacture and erection can be divided into the following processes (Ledbetter, 2001b):

- System design
- System (component) manufacture
- Wall or window (layout) design
- Wall or window fabrication
- Installation

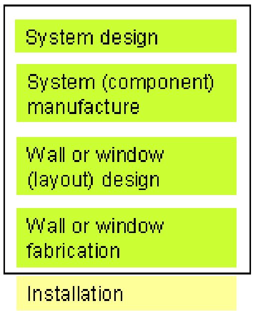
These processes are widely different in terms of skills, plant and culture. They may all take place within a single company or separate companies. The different forms of specialist companies are (CWCT, 2001), Figure 3.11:

- Fully integrated curtain wall company. It can produce a fully bespoke facade from design through to assembly and hand over on site.
- Bespoke curtain wall manufacturer. It restricts its activities to design and manufacture and they do not install on site.
- System supply company. It designs and produces aluminium profiles and other components but it does not involve in the design or fabrication of walls or installation
- System fabricator. It designs and manufactures facades and windows using profiles and components supplied by a system company.
- System fabricator and installer. It installs on site in addition to manufacturing the components ready for installation.
- Curtain wall installer. It is responsible only for the erection of a curtain wall.
- Management sub-contractor. It is the company that takes sole responsibility for all aspects of a wall under management sub-contracting system.

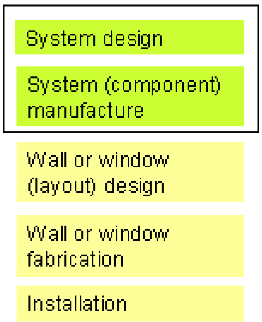
The models described above are the basic forms that companies follow; however, the descriptions allow an overlap and grey areas of activity exist that a company may include within their business or may outsource. “In practice there are a whole variety of companies in the facade supply chain and probably no two are the same” (CWCT, 2001).



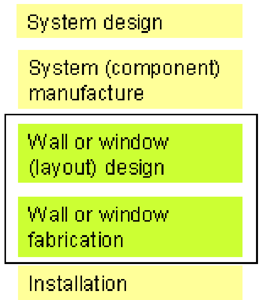
a) Fully integrated companies



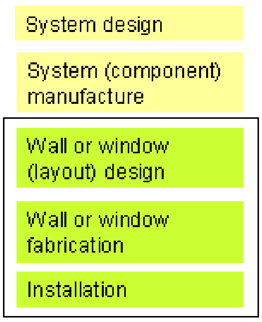
b) Bespoke curtain wall manufacturers



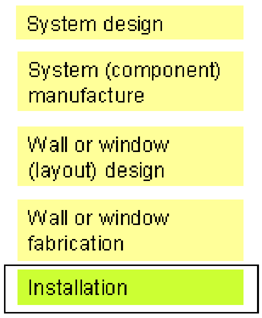
c) System supply companies



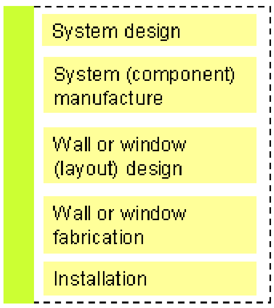
d) System fabrication companies



e) System fabrication and installation companies



f) Curtain wall installation companies



g) Management sub-contractor

Figure 3.11 Forms of cladding specialist contractor (adapted from CWCT, 2001)

3.4 Recent research on cladding

The UK cladding industry has long been criticised for its weakness, inability to take up technology-based research results and fragmentation (Bone 1990; Connaughton, Jarrett, and Shove 1994). In addition, the issues common across the whole construction industry also exist in the cladding sector, such as adversarial attitudes, low productivity, perceived inability to innovate and slow adoption of new technology and modern management methods (McGeorge & Parlmer, 2002). A number of significant research projects focusing on cladding have been carried out from the management perspective.

Curtain Walling for the Construction Industry (Bone, 1990) was published by the National Economic Development Office on behalf of the NEDC Construction Industry Sector Group. The primary object of the research was to identify practical measures by which the competitive position of UK-based suppliers of curtain walling could be improved, and communicate these to the industry. The research report gave an overview on the cladding market, industry and education resources, and reached a series of important conclusions, including "the size of typical UK suppliers is too small to be effective against foreign competition", "there is a need for acceptable performance standards", and "there should be a single voice for the industry".

A Comparative Study of the Facade Industry in the UK, Europe, Japan and the USA (Ledbetter, 1992) drew comparisons between the UK industry and the rest of Europe, Japan and USA, on the nature and structure of the facade industry, education and training, and standards and quality control, which provide objective data indicating the strengths and weaknesses of the British curtain walling industry compared with that in other countries and the reason for the curtain walling import surge in the UK. This report exerted huge influence on the following industry actions and research initiatives.

Innovation in the Cladding Industry (Connaughton, Jarrett, and Shove, 1994) was carried out for the Department of the Environment (DoE) to guide its sponsorship of the cladding industry and to test a methodology for similar studies relating to other areas of construction. The report aimed to understand the business environment, culture, and attitudes shaping the industry and influencing its ability and desire to innovate. Therefore, the organisation and economics of the UK cladding industry were analysed and the main findings concluded: "*The UK cladding industry is weak and unable to take up most conventional technology-based research results; The UK cladding industry is fragmented. This determines the way it innovates. Only changes in the industry's structure and interactions will change its capacity for innovative action.*" These findings provide essential support for the author's idea to restructure the cladding supply chain.

Facade Engineering - a Research Survey (CWCT, 1994), funded by DoE (No. PECD/7/6285), is a research strategy for the cladding industry. The CWCT industry members were invited to participate in a survey to identify the research needs, pure and applied, of the industry. The areas of research were very much drawn from the experiences of the practitioners coming from the members whose interests range from building ownership to facade manufacturing, and reflect known failures or shortcomings and also the doubts encountered during facade design. The main output was a research agenda covering specification and design, materials and processes, testing, management, service life, green issues, export, and innovation.

Fabric 2006 is a fabric industry sector innovation and research strategy for the Department of the Environment (DoE) (Ledbetter, 1996). This strategy set out a vision for the sector as a major contributor to the construction of comfortable buildings of good appearance and with low energy use. Wide industry consultation was used to identify key issues for the sector and the subsequent actions that would achieve the vision. The actions were prioritized in terms of their importance and effectiveness and were linked directly to the five Business Plans that the DoE produced: Environment, Health and Safety, Motivation, Process and Commercial Framework, and Technology and Performance, which set out how funding would be managed and allocated.

FMEA Applied to Cladding Systems (Layzell & Ledbetter, 1999). Failure Mode and Effects Analysis (FMEA) was firstly introduced into the aerospace, defence and automotive industries in 1960s and 1970s, and adapted to limit the high commercial risks of some large civil engineering projects. FMEA is a method of identifying potential failures and showing which are most likely to occur. Firstly all failure modes are identified. Secondly the causes are identified along with the likelihood of them being discovered. Finally a weighting is given to the consequences of failure. The rankings (suitable weighted) of occurrence, non-detection and severity will yield a priority risk number (PRN). Attention is then focused on the eradication of faults that result in the highest PRN'S.

Computer-Integrated Manufacture of Cladding Systems (CIMclad) (Agbasi et al. 2001a, 2001b, 2001c, 2002, 2004, Kalian et al. 2001, 2002a, 2002b) was a two year LINK project funded by EPSRC and DETR, led by Loughborough University and Leeds University. The project initially focused on rainscreen cladding, which was to serve as a pilot for the wider cladding sector. It was divided into five work packages with the following objectives (Agbasi et al., 2001a):

- To establish the potential for process improvements through standardisation of procedures and more efficient use of IT;
- To consolidate and state more formally a set of standard performance specifications for layered cladding walls;
- To develop a product model to support the specification, design, manufacture and construction of layered cladding walls;
- To implement and test these concepts via fast-track implementations and industrial

deployment of standard object-oriented CAD technology;

- To propose a road map for the cladding sector as a whole to realise computer integrated design and manufacturing in the context of wider development within the construction industry.

This project tried to integrate the cladding manufacturing process through standardisation and IT (Watson, 2003), and a flow chart for rainscreen design and procurement from design to Installation was produced (Kalian et al., 2001), Figure 3.12.

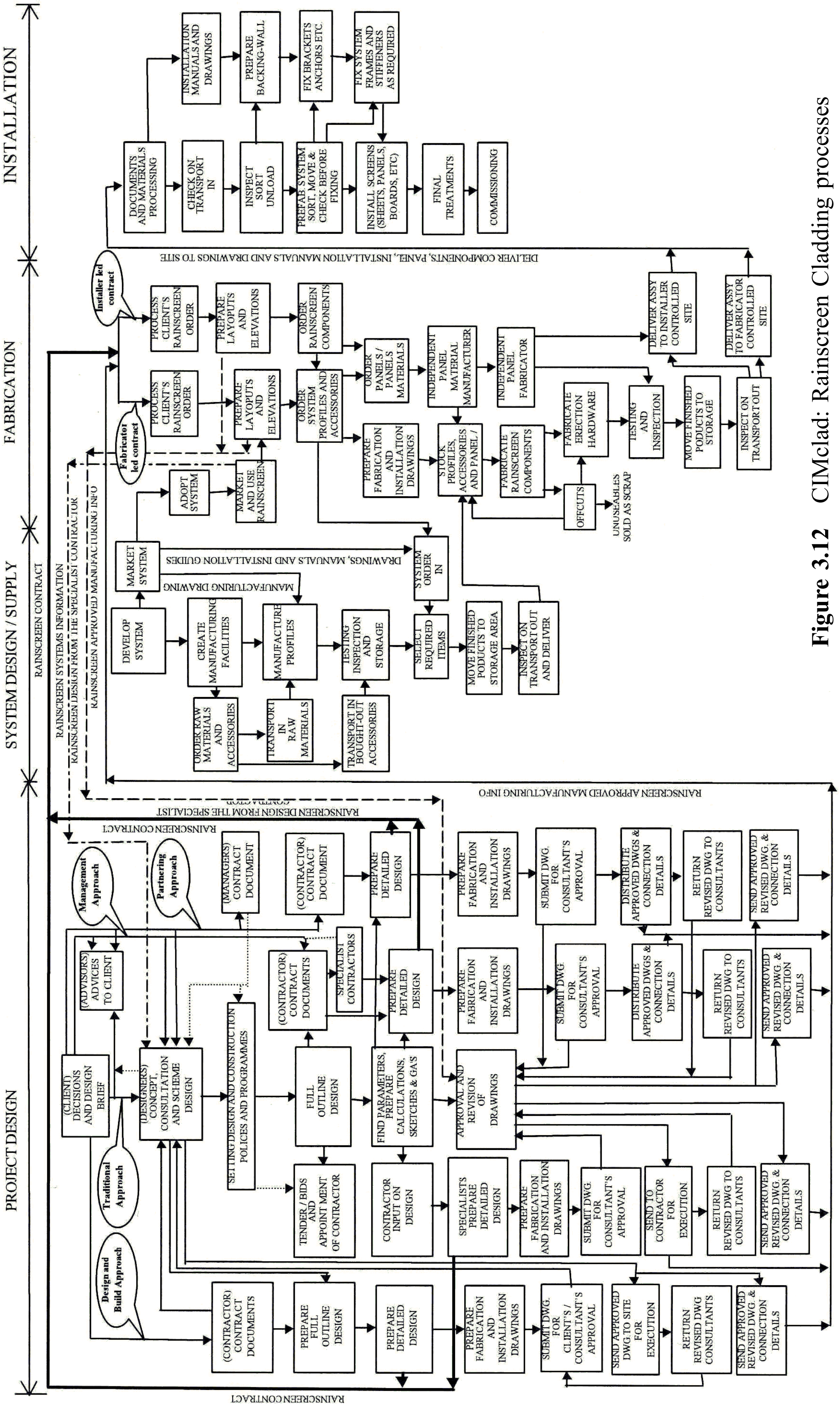


Figure 3.12 CIMclad: Rainscreen Cladding processes from design to Installation (Kalian et al., 2001)

Cladding Interface Standardisation Strategy (CladdISS) is also an EPSRC/DETR project funded through the LINK scheme to develop a standardised strategy for the design and management of window and cladding interfaces，carried out by Gibb, Sutherland and Pavitt at Loughborough University (Pavitt, Gibb and Sutherland 2001, Pavitt 2002, Pavitt and Gibb 2003a, 2003b). Based on a sequence of early research on interface management and prefabrication (Gibb 1994, Gibb 1995, Pavitt and Gibb 2001), it categorises the three types of interface management: physical, contractual and organisational (Figure 3.13) and claims failure to address any of these issues could reduce productivity and quality, and increase waste and costs. The whole cladding procurement process could be divided into twelve phases and reviewed at six points as CladdISS described, Table 3.1. An interactive compact-disk read-only memory (CD ROM) software tool that provides a strategy for optimizing technical and management aspects of cladding interfaces was produced. The framework was validated by an industry survey (Pavitt, 2002).

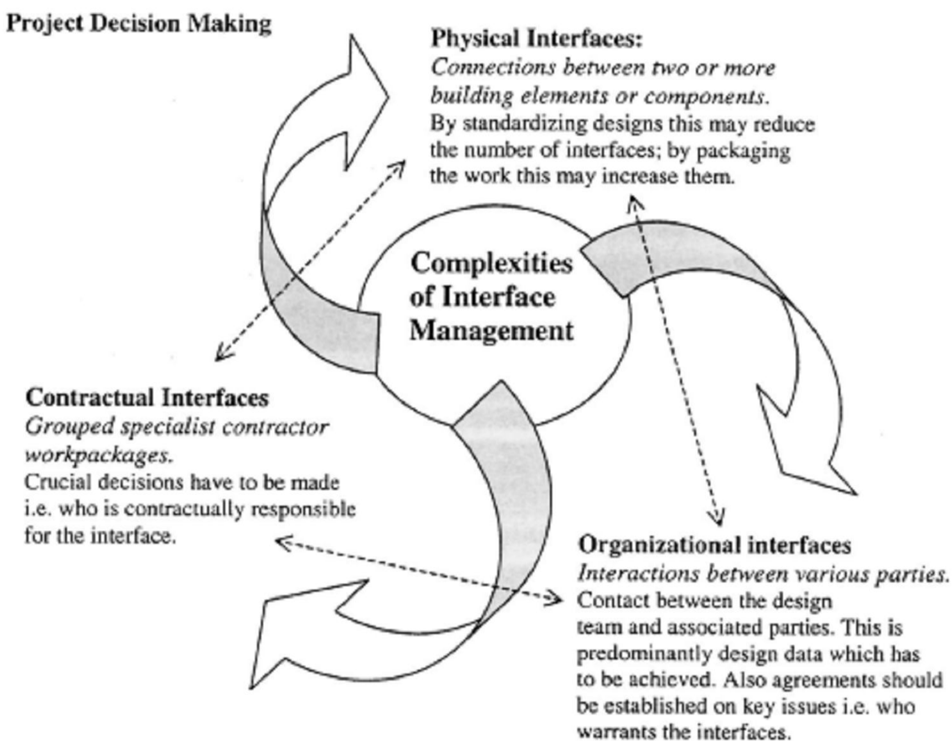


Figure 3.13 Project decision-making problems concerning interface management (Pavitt & Gibb, 2003b)

Phase 0	Demonstrating the need	
Phase 1	Conception of need	CladdISS review 1
Phase 2	Outline feasibility	
Phase 3	Substantive feasibility and outline financial authority	CladdISS review 2
Phase 4	Outline conceptual design	
Phase 5	Full conceptual design	CladdISS review 3
Phase 6	Co-ordinated design, procurement and full financial authority	CladdISS review 4
Phase 7	Production information	
Phase 7a	Manufacture	
Phase 8	Construction/Assembly	CladdISS review 5
Phase 9	Maintenance /facilities management	
Phase 10	Demolition/Decommission	CladdISS review 6

Table 3.1 Project phases and review points on cladding procurement (Pavitt, 2002)

Communicating down the Cladding Supply Chain is a DTI PII project (No. 39/03/635), completed by Ledbetter (2003, 2004a). In that research, the cladding supply chain was thoroughly reviewed and clarified as 'a supply net' due to its procurement characteristics. It stated that performance specification allows decision-making to occur at the most appropriate level but the issue of appropriate competences exists, information flows need to be organised and interactive specification will be beneficial. A web-based software has been developed initially to facilitate communication through the supply net and the barriers to implementation are identified as the ownership of information and responsibility for information supply.

Summary

This section reviewed a number of significant recent research projects focusing on cladding. Critical issues, including interface management, communication, ICT usage, standardisation, innovation and industry restructure, have been intensively studied. The results of these projects are very valuable for the development of the cladding industry and are the cornerstones of this research. However, there is a lack of knowledge of management and decision making within the context of cladding supply chain. Therefore, the following sections will survey the literature in a broader context of the whole construction industry and other industries.

3.5 Construction management concepts and initiatives

3.5.1 Overview

The building cladding sector is a representative part of construction industry and the cladding supply chain is located in the construction supply net. The construction industry has long been one of the economic pillars in Britain. It accounts for about eight per cent of Gross Domestic Product (GDP), and employs more than one million people. However, the industry has been criticised for its low productivity, fragmentation and adversarial attitudes for several decades (Woudhuysen and Abley, 2004).

In attempts to improve the industry performance, calls for culture shift to change its perceived inability to innovate and its slow adoption of new technology and modern management methods never stop. They range from the Simon Report (1944), the Emmerson Report (1962) and Banwell Report (1964), to the Latham Report (1994), and more recently, the Egan Reports (1998, 2002). Meanwhile, many management concepts originating from other industries have been introduced into the construction industry, and initiatives such as PFI and Prime contracting relating to supply chain integration were conducted by government and related organisations.

3.5.2 New management concepts

A number of recent construction management concepts are reviewed and the link between them is explored below.

Value management

Value management has its origins in the American manufacturing industry during World War Ⅱ(Miles, 1967). It is a function-oriented approach aiming at enhancing the value of a product, system or supply by "identifying and eliminating unnecessary costs and achieving the required performance at the lowest life-cycle project cost" (Fong and Shen, 1999). In the construction industry, this approach varies in different countries. For instance, USA, Europe, Japan and Australia all have their own systems (McGeorge and Palmer, 2002). In the UK, a European standard EN12973:2000 provides a guide for the practice of value management.

Constructability/Buildability

The terms 'constructability' and 'buildability' occur exclusively in the domain of the construction industry. Albeit the former term "encompasses wider system boundaries" than the latter one, they are commonly treated as synonymous in practice for simplicity's sake (McGeorge and Palmer, 2002). The Construction Industry Research and Information Association (CIRIA) (1983) in UK defined buildability as 'the extent to which the design of the building facilitates ease of construction, subject to the overall requirements for the completed building'. The definitions of constructability developed by the Construction Industry Institute (CII) (1986) in USA and the Construction Industry Institute (CIIA) (1992) in Australia expanded the scope of the concept to a wider sense, as "a system for achieving optimum integration".

Benchmarking

Benchmarking is a concept invented by the Xerox Corporation in 1979 (Camp, 1989). The key element of this technique is 'comparison' especially with better performing practices. It is mainly used to improve the competitiveness of organisations through the examination and refinement of their business processes (McGeorge and Palmer, 2002). Benchmarking has achieved increasing awareness and adoption in the construction industry recently (Latham 1994; Construct IT Centre of Excellence 1996; BRE 1996; Egan 1998; McCabe 2001) though its disadvantages, including complexity, high costs and that it is time consuming, were identified early (Lenkus, 1995).

Total quality management

Total quality management (TQM) is a people focused management system which integrates all functions and processes within an organisation in order to achieve continuous improvement of the quality of goods and services. The goal is customer satisfaction (Rampsey & Roberts, 1992; Vincent & Joel, 1995). The definitions of quality differ depending on the reviewing point, such as manufacturing-based, product-based, user-based and value-based; however, they could be translated into a more objective list of principal quality dimensions: performance, reliability, conformance, durability, serviceability, aesthetics, and perceived quality (Evans & William, 1993). Basically, TQM is an attitude whereby customer focus is the main driver of the organisation.

Supply chain management

The concepts of the supply chain have been discussed in chapter 2. Supply chain management (SCM) is "the strategic, tactical and operational decision making that optimises supply chain performance" (Fox et al., 2000). The concept was borrowed from mainstream management disciplines and has found favour with construction management. There have been some notable applications by construction firms, however very little is known about the application of supply chain management in a widespread manner across the industry (McGeorge and Palmer, 2002). Supply chain management has been used to explain the planning and control of materials, information and financial flows "not only internally within a company but also externally between companies" (Chen and Paulraj 2003, Cooper et al. 1997, Fisher 1997). It is a tool rather than a research target in this research.

New product development

New product development (NPD) is a newly proposed idea as a construction process management (Cooper et al., 2005), which considers the mature theories of product development in the manufacturing industry and focuses on the process. This approach treats every project in construction as if it is a new product in manufacturing industry, which enables the use of the theory of manufacturing. Other management elements are adapted to work around the 'new product'.

Summary

The management concepts above, many from other industries, aim to improve the performance of the construction industry from various aspects of process, relationship, quality, and value. They should be able to contribute to a modern industry effectively and have been proven in some other industries. At least, they provide tools and paths to realise so called 'culture shift'. Government departments and relevant organisations have begun to do that, though they may aim at financial benefits in the first instance.

3.5.3 Initiatives and frameworks: attempts to integrate the supply chain

Responding to the reports mentioned in section 3.5.1 and recently introduced management concepts, a number of practical initiatives and frameworks are underway. They have triggered the process of the culture shift in the construction industry.

Private Finance Initiative (PFI)

PFI was initially proposed as a UK Conservative Government policy aimed at reforming the delivery of state activities that could not be privatised for financial or political reasons. In 1997, the incoming Labour Government embraced the policy, renaming it public private partnerships (PPP) (Edwards et al., 2004). Since then PPP/PFI has become one of the key Government policies and over 400 PFI contracts have come into force representing future commitments at 2003 of around £105 billion (NAO, 2003). Under this programme, partnerships between public clients and contractors could be set up. Partnerships UK (PUK), a joint venture founded in 2000 out of HM Treasury with a majority stake held by the private sector, bridges the gap between public and private sectors, and supports and accelerates PFI project delivery. A valuable thing that PUK has done is to create a well-developed database which holds details of more than eight hundred projects (http://www.partnershipsuk.org.uk, accessed 6 Feb 2008).

Procure21 and **LIFT**

In the healthcare sector, National Health Service (NHS), ProCure21 introduces a partnering framework for the NHS. Under the framework, NHS clients are provided with the ability to readily appoint accredited Principal Supply Chain Partners (PSCPs) alongside a pre-agreed commercial arrangement (http://www.nhs-procure21.gov.uk, accessed 6 Feb 2008).

In addition, NHS Local Improvement Financial Trust (LIFT) is a vehicle for improving and developing frontline primary and community care facilities (http://www.p4s.org.uk, accessed 6 Feb 2008). Partnerships for Health (PfH), a joint venture between Department of Health (DH) and PUK, delivers NHS LIFT on behalf of DH.

Building Schools for the Future (BSF)

In the education sector, Building Schools for the Future (BSF) represents a new approach to capital investment. It is bringing together significant investment in buildings and in ICT (Information and Communications Technology) over the coming years to support the Government's educational reform agenda (http://www.bsf.gov.uk, accessed 6 Feb 2008).

Partnerships for Schools (PfS), established in 2004 by the Department for Children, Schools and Families (DCSF) and PUK, is responsible for delivering the government’s secondary school renewal programme, Building Schools for the Future (BSF). BSF is working with local authorities and the private sector to rebuild or renew every one of England's 3,500 state secondary schools during the 15-year lifetime of the programme, and also recently took on responsibility for delivering the Academies, which will see 400 Academies built across the country (http://www.p4s.org.uk, accessed 6 Feb 2008).

Building down Barriers

In the defence sector, Defence Estates within the Ministry of Defence (MoD) combined with DETR to set up and sponsor "Building down Barriers (BDB)' in 1997. They wished to create a learning mechanism for establishing the working principles of supply chain integration in construction. The first phase of the initiative, which is also sponsored by AMEC and Laing from the private sector, ended late in the year 2000. BDB created a process for integrating the supply chain within a construction project, then tested it out and refined it on two live pilot projects for Army Land Command, with AMEC and Laing as 'prime contractor'. A research and development group, led by The Tavistock Institute, has developed and evaluated the supply chain process with its supporting tools and techniques (Holti et al., 2000).

Avanti

Avanti is an approach to collaborative working in order to enable construction project partners to work together effectively, which was sponsored by the UK Department of Trade and Industry in 2002. The participants include most of the largest UK firms in the construction industry and International Alliance for Interoperability (IAI), Loughborough University and Co-construct (http://www.constructingexcellence.org.uk/ceavanti, accessed 8 Oct 2008). The Avanti initiative aims at delivering improved project and business performance through the use of ICT to support collaborative working, apply the Avanti approach by "getting people to work together; providing processes to enable collaboration; and applying tools to support collaborative working". Evaluation of the impacts of the Avanti project showed (DTI, 2007): "

- Early commitment offering up to 80% saving on implementation cost on medium size project.
- 50-85% saving on effort spent receiving information and formatting for reuse.
- 60-80% saving on effort spent finding information and documents.

- 75–80% saving in effort to achieve design co-ordination.
- 50% saving on time spent to assess tenders and award sub-contracts.
- 50% saving on effort in sub-contractor design approval."

Construction Lean Improvement Programme (CLIP)

Echoing 'Lean Construction' set out in the Egan reports (1998, 2002), Building Research Establishment (BRE) carried out a DTI funded Construction Lean Improvement Programme (CLIP), which took the principles of lean thinking from the aerospace, automotive and petrochemical industries and adapted them to construction. CLIP has worked successfully on improving the quality, cost, efficiency and delivery of a product or service to achieve higher levels of customer satisfaction, with over 80 construction companies across the construction supply chain (http://www.bre.co.uk/clip, accessed 6 Feb 2008). What needs extra advocacy here is the need for a commercialised third party to push the technical integration of a project.

Summary

These initiatives provided platforms where players may work together and a culture shift could be enabled. Valuable experience and lessons have been gained for the future development of the construction industry.

3.6 Communication and knowledge management in construction

The construction industry has a poor reputation for the communication between its organisations and individuals (Emmitt and Gorse, 2003). As commonly recognised by many practitioners and researchers, communication is the weakness of the industry (Dainty et al., 2005). A series of governmental reports (Simon 1944, Emmerson 1962, Barnwell 1964, Latham 1994, Egan 1998, 2002) have consistently criticised the apparent lack of effective communication within the construction sector. These reports attempted to encourage collaboration and improve information exchange, and inspired in-depth thinking on “the fragmented nature of the sector, lack of co-ordination, separation of design and construction activities, lack of trust and adversarial relationships”; they are all “factors that hinder rather than promote effective communication”(Emmitt and Gorse, 2003).

One of the most widely cited research projects on communication in the construction industry, ‘Communications in the Building Industry: The Report of a Pilot Study’ (Higgins & Jessop, 1965), was to indentify the type of interaction, relationships and groups that make construction’s social systems. A following report, ‘Interdependence and Uncertainty’ (Building Industry Communications, 1966) indicated the increasing fragmentation and deepening specialisation in the construction industry had dramatically to contributed the difficulty of communication.

Recently, there has been more interest in communication research within the International Council for Research and Innovation in Building and Construction (CIB). In particular, Working Group 96 ‘Architectural Management’ has witnessed several attempts at dealing with communication, both explicitly and implicitly (e.g. Nicholson 1992, Emmitt 1999) and Working Group 102 ‘Information and Knowledge Management in Building’ has carried out some important work in this area. Additionally, the papers and debates published in the proceedings of the Association of Researchers in Construction Management (ARCOM) conferences, which focus on communication, have steadily increased (e.g. Dainty & Moore 2000, Gorse et al. 2000a, b, c, d, 2001,2002, Hugill 2000, Wild 2001, Green et al. 2002, Moore & Dainty 2002).

At the same time, an interest in knowledge management (KM) surged in the West from the mid-1990s. Knowledge management is “the process by which information is created, captured, stored, shared, transferred, implemented, exploited and measured to meet the needs of an organisation” (Emmitt and Gorse 2003, Boisot 1998, Egbu et al. 2001).

Early 1990s KM initiatives in firms such as BP, Chevron, Shell, Hewlett Packard, Buckman Labs and Xerox, and the pioneer of intellectual capital reporting in Skandia (1994), all pre-date the academic KM publishing boom. The emergence of the knowledge era as an integral part of the global economy is leading to dramatic changes in the business environment (Anumba et al, 2005). Knowledge management and its manifestation in the expertise of people are now seen as the greatest creation of value for organisations. In a recent Competitiveness White Paper, Our Competitive Future: Building the Knowledge Driven Economy, a knowledge economy was defined as one in which the generation and exploitation of knowledge have come to play a predominant part in the creation of wealth (DTI, 1998). Similarly, the OECD report The Knowledge-Based Economy suggested that what is created in a knowledge economy is a network society, where the opportunity and capability to access and join knowledge and learning-intensive relations determine the socio-economic position of individuals and firms (OECD, 1996).

Many construction organisations have sought to ensure that the knowledge of their people is made available at the right place and time. At Arup, they found that the size of the firm was making it increasingly difficult to 'know who knew' the answer to a particular problem. In response, a web-based knowledge sharing tool was developed that now allows Arup to locate experts throughout 7000 staff in a matter of seconds. Each individual from chairman to new recruit can quickly and easily share their interests and expertise with the rest of firm (Anumba et al., 2005).

Knowledge management should be adopted as a strategy in order to generate informed decision-making, as shown in Figure 3.14.

However, the knowledge sharing is not a popular culture in the construction industry, and Marshall and Sapsed (2000) highlight that;

- Knowledge resides in the heads of senior engineers who have gained it through experience;
- Many of these engineers see 'knowledge as power' and do not readily share it;

- Many experienced engineers are approaching retirement;
- There is limited knowledge transfer to more junior staff.

Therefore, a knowledge management and communication system which enables ‘knowledge holders’ to share their ‘power’ needs to be established with the aims of: achieving culture change, mentoring, appraisal and reward, besides technology (Anumba et al., 2005).

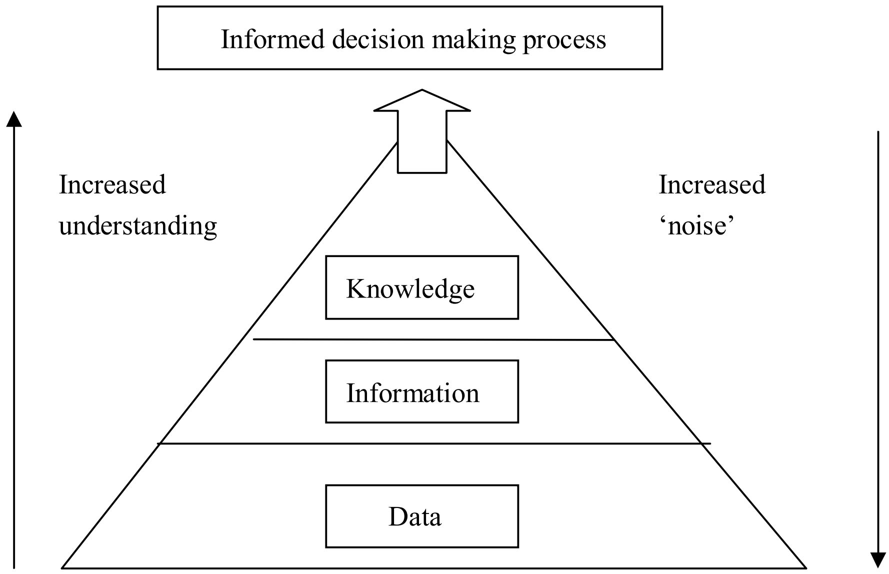


Figure 3.14 Knowledge support for decision-making (adapted from Anumba et al., 2005)

3.7 IT in Construction

Computing and communication technology, also commonly known as Information Technology (IT), have been radically transforming the way we live, learn, work and play (Capron, 2000). Although it is widely acknowledged that the construction industry is lagging behind other industries in adopting IT (Department of Environment, 1995), the penetration of computers in construction has been gathering pace in recent years due to rapid improvements in computer hardware and software (Stevens, 1991; CICA, 1993; CICA, 1996). Today, a large number of software packages are available to all disciplines of the construction team at all stages of the construction process. They provide support for a broad range of activities such as computer aided design and drafting, building visualisation, design appraisal, project management, information storage and retrieval, cost estimating, structural analysis, on-site management, facilities management and others (Sun and Howard, 2004).

For construction professionals, the initial surge of enthusiasm for computer applications started in the early 1960s. There was an optimistic view of the computer's potential as a supporting tool for design and construction and the time needed to develop this potential (Stevens, 1991). By the early 1980s, the initial excitement had been replaced by a greater realism about what the computer could offer. The change of opinion was caused by a combination of the high capital cost of computing hardware and limitations of the existing software systems. In 1985, an AIA survey in the United States revealed that many architectural firms did not make use of the computer because they believed 'it would cost too much' (Architectural Record, 1985). On the computer performance aspect, there were also some constraints, including small storage capacity, processing speed and inadequate I/O facilities.

Since the mid 1980s, the penetration of computers in the construction industry has been accelerating thanks to the rapid development in computer hardware and software. The steady increase of computer ownership and IT applications among construction practices has been confirmed by a series of surveys by RIBA, CICA and other professional organisations (RIBA Journal, January 1995; CICA, 1993). In 1995 the UK government commissioned a study, 'Construct IT: Bridging the gap'. It was intended as an Information Technology strategy for the UK construction industry. The strategy identified two key aims for the future use of IT in the construction industry:

- Integrated project communications frameworks, supporting closer teamwork.
- Integrated industry-wide information systems comprising standard component listings, building performance benchmarks, best practices, etc., to improve and inform construction projects.

In the cladding sector, a number of research projects, including CIMclad (Agbasi et al. 2001a, 2001b, 2001c, 2002, 2004, Kalian et al. 2001, 2002a, 2002b), CladdISS (Pavitt, Gibb and Sutherland 2001, Pavitt 2002, Pavitt and Gibb 2003a, 2003b) and 'Communicating down the Cladding Supply Chain' (Ledbetter 2003, 2004a), have emphasised the importance of IT and made good use of IT facilities.

3.8 Reference from automotive industry

Some industries that were perceived to perform better, such as the automotive industry, already had relatively mature 'web-based systems that linked multiple businesses together for the purposes of trading or collaboration', which are so called 'e-hubs' (Daniel et al., 2003).

E-hubs tend to be classified in terms of what they exchange, e.g. products and services, and how they exchange it, for example, either systematic sourcing and negotiated contracts, or spot sourcing and commodity trading (Kaplan and Sawhney, 2000). The commercial e-hubs often provide an e-market to profit from commission fees rather than an online decision making platform.

In the automotive industry, the most powerful e-hub – 'Covisint' – was launched in 2000. It was a consortium exchange where the ownership was shared between competing firms, Ford, General Motors, DaimlerChrysler, Renault-Nissan and Peugeot Citroen. Those founder members anticipated significant component price reductions and customer responsiveness by combining purchasing economies of scale and internet technology (Howard et al., 2006). However, only three years later, the e-hub that was supposed to transform the automotive industry was disassembled and sold to Freemarkets, a 'third party', which in turn was purchased by Ariba, another third party.

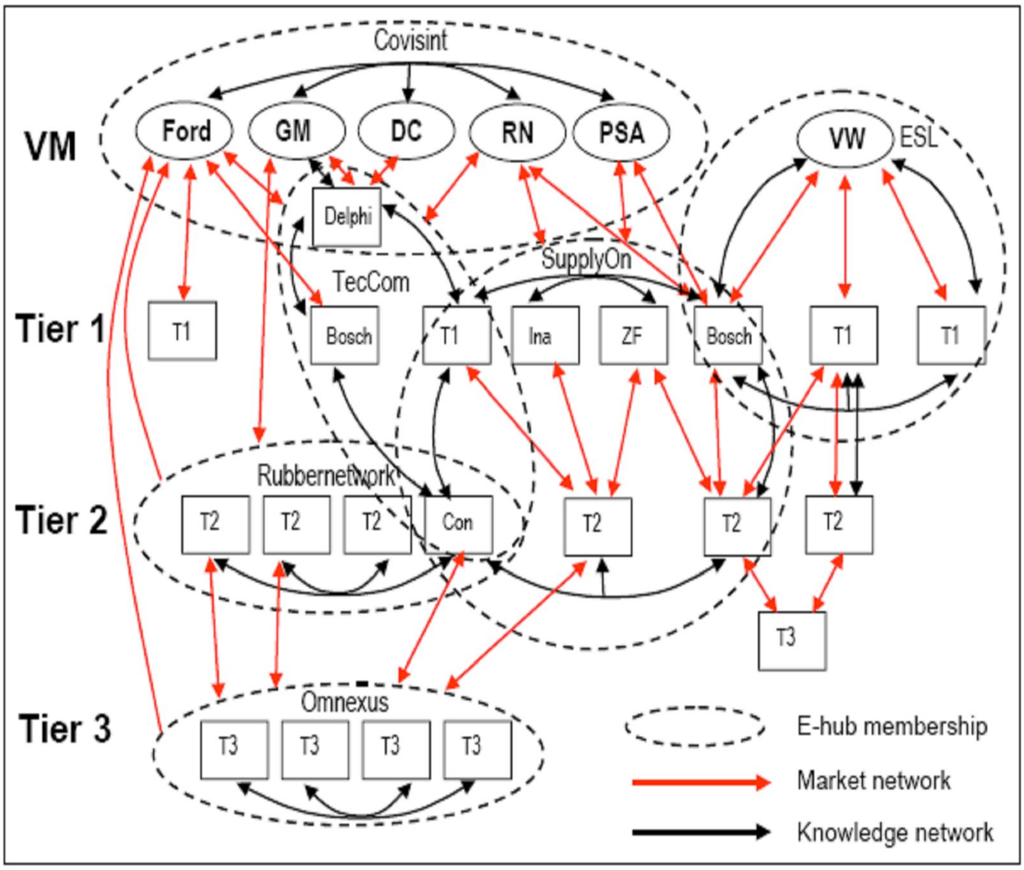


Figure 3.15 Automotive industry e-hubs (Howard et al., 2006)

The reasons for the failure of Covisint is that individual manufacturers and component suppliers were already developing their own solutions and were reluctant to join Covisint over fears of accepting a subordinate role (Howard et al., 2006). However, the inherent defects originated from lack of trust between rival players which placed great limitation on this e-hub.

On the contrary, many e-hubs run by a group of non-competing firms or one non-trading firms work effectively in the automotive industry, and they form the current e-market network (Howard et al., 2006), Figure 3.15. This may be referenced for the future development of hubs in the construction industry.

3.9 Decision making

Decision-making has been extensively studied in a wide range of industries and conditions; however, the roots of decision research are planted in social science, in which penetrating analysis is convincing. The development of decision theories provides a fundamental understanding for the mechanism of decision making.

The evolution of decision support systems

Simon (1960) claims that organisational decision making is a linear process, moving through three stages: intelligence, design and choice. A number of researchers further developed the theory of linear processes (Phillips, 1989; Humphreys and Berkeley, 1986; Humphreys, 1989). However, Nappelbaum (1997) argues that the decision-making group sharpens the description of the problem by cycling through option descriptions, value judgments and instrumental instructions, reducing discretion in how these may be defined in developing structure and spiralling toward a prescribed choice. This process is so called "the circular logic of choice".

Humphreys (1998) conceptualised a five-level decision-making structure, the "decision-spine", in which each level is associated with a different kind of discourse concerning how to structure the constraints at that level. However, the hegemonic structure of a single decision-spine is contested by a few different views of the core process, including decision making as learning (Schein 1987, Argyris and Schon 1996, Senge 2003) and decision making as an integral function of the authoring of collective narratives (Imas, 2004). Therefore, a symbolic decision-hedgehog was developed by Humphreys and Jones (2006, 2008). This decision spine is rooted in cognitive operations at level five, "exploring what needs to be thought about", which extends throughout the unbounded body of a decision-hedgehog.

Decision making in the context of supply chain

The theory of the decision hedgehog is a comprehensive model for a complex and modern industry. The modern supply chain is a network of multiple organisations and relationships, which includes the flows of information, services or products, and funds between different participants (Xue et al., 2004). The decision makers within the cladding supply chain may include all the participants, i.e., the client, design team, main contractor, cladding specialist contractor and a range of suppliers (Du, 2007). They form the decision-making group. The body of the decision-hedgehog can be seen as a mechanism to learn from previous decisions and their effects and prepare for new decisions.

The considerations for decisions of cladding design and procurement have been discussed in section 3.3. Decisions are made using information and knowledge to create new ideas and solve problems (Emmitt and Gorse, 2003). However, the decision makers have uneven knowledge of facade engineering (Ledbetter, 2006), Figure 3.16, which makes the communication and collaborative decision-making necessary. Emmitt and Gorse (2003) claim that communication and the availability of accurate and current information are central to the decision-making process.

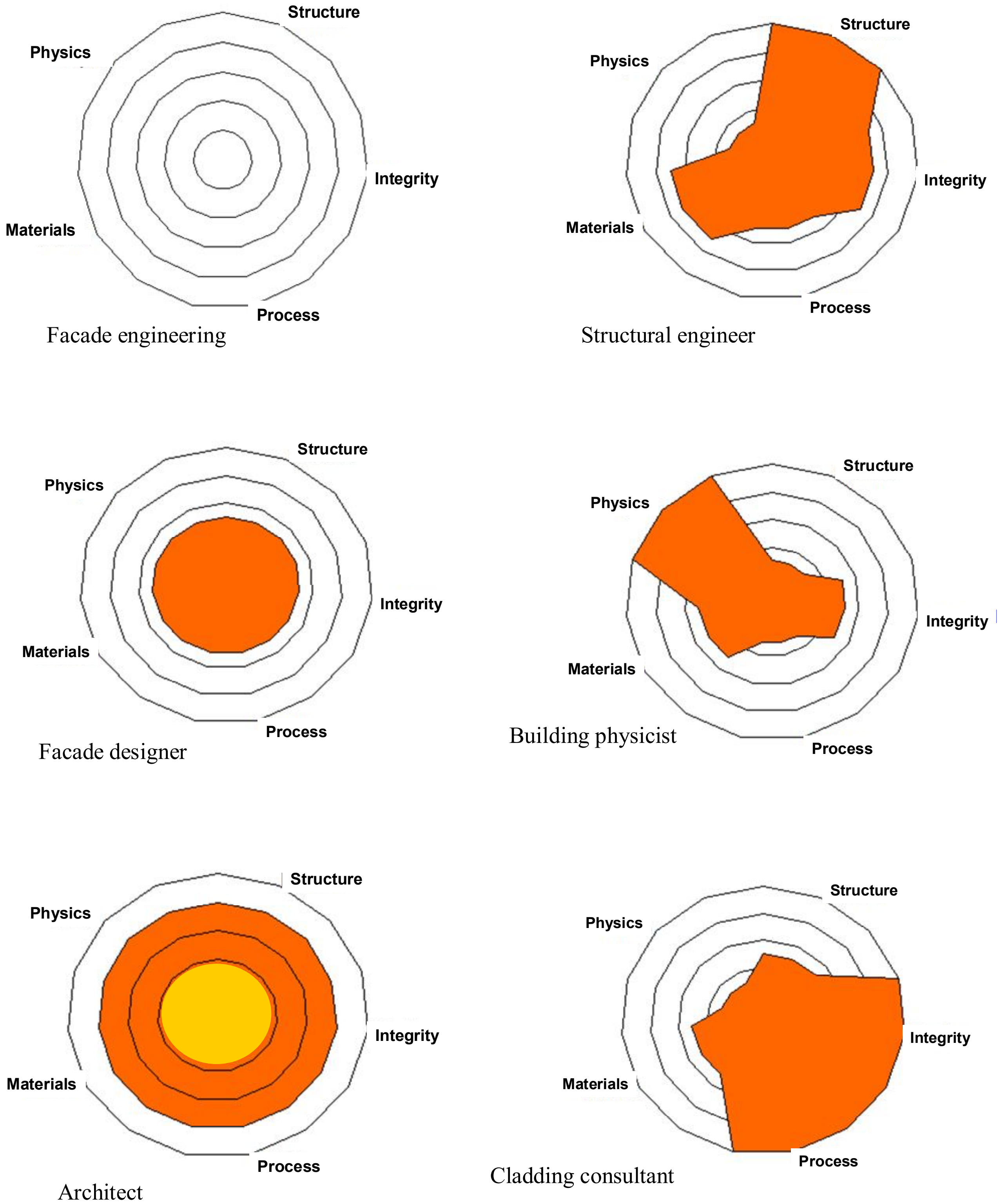


Figure 3.16 Facade engineering knowledge scope and related professionals' skills sets (Ledbetter, 2006)

3.10 Summary of literature review

The literature review covered facade engineering, supply chain management, human communication and computing, and decision making theories. However, there is lack of systematic literature on decision making in collaborative cladding design and construction, especially on how informed decisions should be made under complex and changing circumstances. This shows the need for the research and its outcomes, and that great potential could be gained.

Cladding materials and technical solutions are rapidly developing, and the processes of design and procurement become more and more complex. These factors contribute to deep specialism and fragmented supply chains, in which communication is insufficient and the relationships are commonly adversarial.

There have been a number of research projects and practical initiatives carried out in the construction industry for integrating the supply chain and for collaborative working between the participants involved. In the cladding sector, the recent research projects contributed significantly on interface management, commutation and ICT usage.

Decision making is important for both cladding design and procurement. Accurate and timely information is critical for decision making, especially under complicated circumstances. There should be a strategy for integrated decision making within the context of cladding the supply chain. However, literature of this is scarce. This research explores this issue, in particular, from the perspectives of adequate communication, information supply, knowledge management and contemporary ICT facilities.

Chapter 4 Methodology

4.1 Introduction

As stated in Chapter 1, the aim of this research is to study the design and procurement process within the context of the cladding supply chain, in particular the decision making process. In order to achieve the aims and objectives of this research, it is important to determine the most appropriate methodology for this study. Scandura & Williams (2000) noted that the impact of management studies often depends “upon the appropriateness of the research methods chosen”. This further highlights the importance that the researcher needs to select the right approach if the end-result is expected to be valuable and meaningful from a management perspective.

This chapter provides an explanation of the methodology, which has been used in this research. It can be divided into several parts, including methodology discussion, data collection, data analysis, and framework development and validation.

4.2 A discussion of research methodology

4.2.1 Research approaches

According to Saunders, Lewis and Thornhill (2003), there are two different research approaches: the deductive approach and the inductive approach. Deduction entails the development of a conceptual and theoretical structure, which is then tested by observation. In the inductive approach, general inferences lead to the development of theory from the observation of empirical reality (Gill and Johnson, 2002). According to Beveridge (1950) in

Babbie (1972), "in induction one starts from observing data and developing a generalization which explains the relationship between the objects observed".

The deductive approach is a research approach "involving the testing of a theoretical proposition by the employment of a research strategy specifically designed for the purpose of its testing" (Saunders et al., 2003). The inductive approach is the research approach "involving the development of a theory as a result of the observation of empirical data" (Saunders et al., 2003).

In this research, the author adopted the deductive approach but based on observations of industry to develop a concept of an integrated decision making framework for cladding procurement after a detailed literature review. To test the validity of this framework a survey was designed to examine whether the framework would work in industry.

4.2.2 Research methods

There are two main kinds of research methods usually employed in research: the quantitative method and the qualitative method. The quantitative approach often defines categories of the phenomenon before the investigation, and assigns numbers to these categories, and generally uses data collection methods such as, questionnaires, observations and interviews. In contrast, the qualitative approach often provides no numerical examination of the phenomena, and usually uses unstructured or semi-structured interviews, or observations to collect data (Marlow, 1993). Researches in modern construction management have benefited from the merits of both methods (Seymour and Rooke, 1995, 1998).

In this research, the quantitative method was adopted by using a questionnaire, while the qualitative method was employed in interviews and observations.

4.3 The phases in this research

This research is an exploratory research, based on a literature review and observation of the cladding industry. The phases of the research are shown in Figure 4.1.

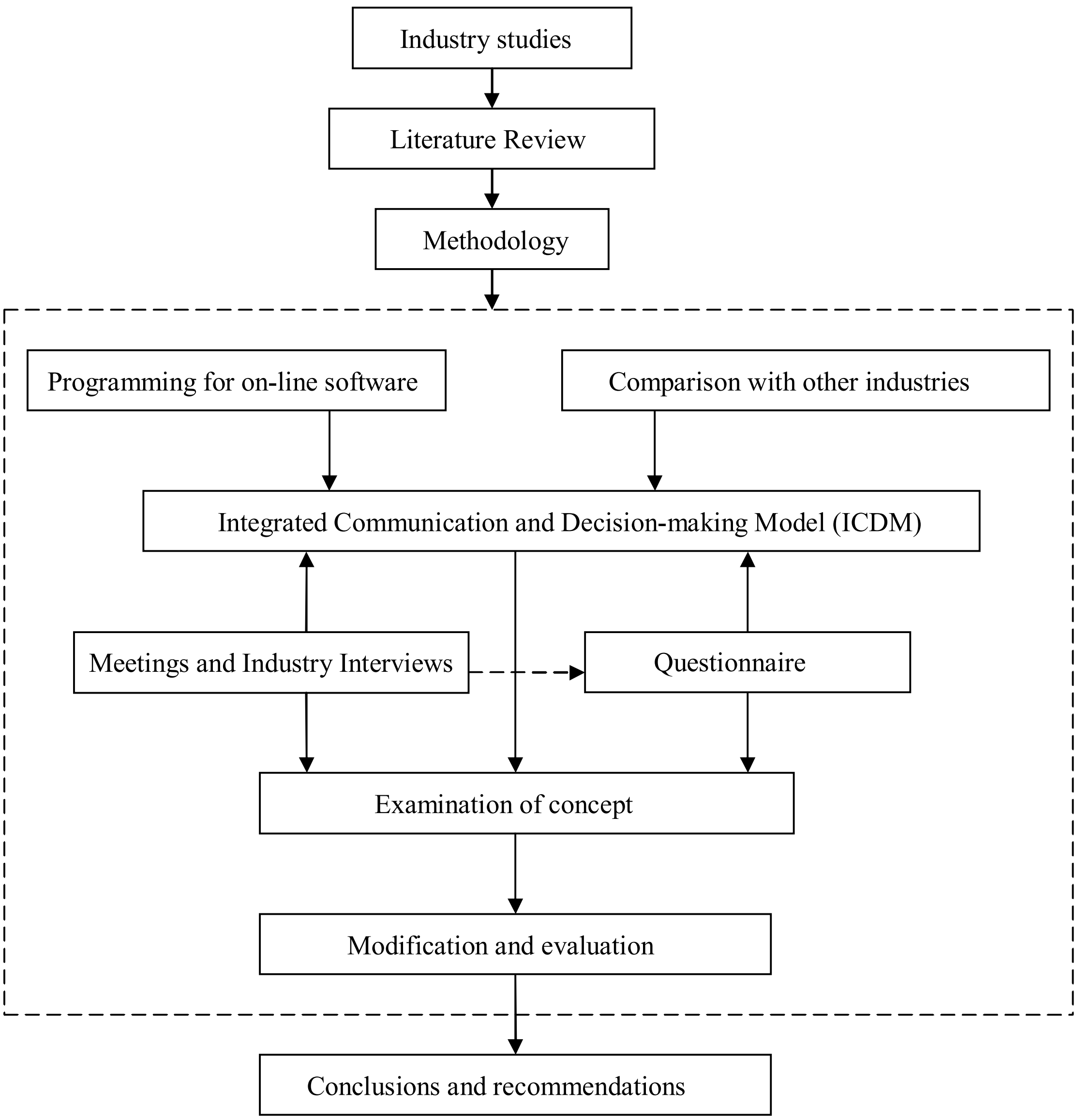


Figure 4.1 The diagram of the research phases

In the literature review, it was identified that information supply and communication are the key factors of informed decision making. At the same time, contemporary Information Technology provides improved methods for managing data and communicating. Therefore, programming was carried out to explore the feasibility of using on-line software in the decision making process within the cladding sector. At the same time, a further investigation on industries that are perceived to perform better was carried out to gain the experience and lessons to be learnt from them.

After this, an integrated decision-making model, tailor-made for the cladding industry, was proposed. The initial idea was presented and discussed in seminars, conferences and at CWCT meetings. Advice from academia and industry was taken into the framework. To further develop and validate it, a series of informal but guided interviews with experts from the industry were conducted, and an on-line questionnaire was used to collect essential quantitative data from the industry practitioners.

Responding to the data collected and analysis results, a number of modifications on the conceptual model were made. A final step of evaluating the functionality and in particular the applicability of the conceptual model was undertaken.

4.4 Developing software

Initially, facing the fragmented communication and information transfer, and the utility of the information technology, there was an attempt to bring project participants to a web-based communication platform as descried by Ledbetter (2004a). The author programmed with perl and MySQL database, to explore the feasibility of using a project level database on-line. A number of postgraduates from civil engineering, management and computer science were invited to join a workshop to test the feasibility of the software and its interface.

The author attempted to organise the information structure and identify information sources, however, it was found difficult to resolve the issue of information sources under the current communication model. This online software mainly replicates the current communication route; however, problems were found with the sourcing of external information and flexibility of the format. So a further exploration of the communication model was carried out.

4.5 Comparison with and references from other industries

To identify the approaches used in other industries', several industries were identified for investigation, including the automotive, aerospace and retail industries. Among them, it was found that the automotive industry has the greatest similarity with the construction industry; therefore, some ideas were adopted from the automotive supply chain, especially the concepts of an 'e-hub' and third party involvement, were examined, modified and introduced in the author's proposed communication and decision making model for the cladding industry.

Construction is almost unique in its need to build supply chains specific to a short-term project and to build design teams on a project by project basis. Other industries have less need of an information exchange but make extensive use of on-line commercial networks for procurement (an e-marketplace).

In other industries, decision making software is used intra-company not as an extranet with many companies participating.

4.6 Modelling for cladding industry

One of the main features of the author's communication and decision making model is a third party involved as a 'hub', for the communication and decision-making processes in the cladding supply chain. The hub plays a role of information and communication exchange rather than an e-marketplace. Centred around the hub, a conceptual model for integrated decision making, namely 'Integrated Communication and Decision-making Model' (ICDM), was proposed.

4.7 Data collection and analysis

4.7.1 Methods of data collection

Data collection methods may be divided into the primary data collection and the secondary data collection. As Marlow (1993) explains the secondary data is the form of data sets that have been previously collected, and it is noticed that "data quality is always a concern" (Schutt, 1999). However, no similar research has been undertaken before in this field and there was insufficient existing data for the author to study to obtain secondary data. Therefore, in this research the author relied on primary data collection. The data were obtained mainly through a self-administered questionnaire and interviews with industry practitioners.

In this particular research, both quantitative and qualitative methods were chosen. The quantitative data, which were collected specifically for the particular research project being undertaken, were obtained through a questionnaire circulated in the industry. The qualitative data was gained from interviews with industry professionals and some open questions of the questionnaire.

4.7.2 Conferences and meetings

The author presented parts of this work at a departmental seminar and three international conferences, comments were received and networks were set up. The initial ideas and framework were examined and refined following comments from the participants from industry and academia.

CWCT holds Technical Meetings for its members every year and hosts a cladding industry conference every two years at Bath University. The author not only took those valuable opportunities to learn the realities and trends of the industry, but also made conversation with the experienced representatives to gain their opinions on the cladding supply chain, communication and decision making issues, and suggestion on this research.

4.7.3 Interviews

The informal but guided method of interviewing retains the advantage of the informal approach but provides the interviewer with an outline of the topic and the issues to be explored (Cooligan, 1994). The interviews in this research were mainly conducted in an informal and semi-structured way. 34 senior practitioners from different parties, including architects, facade consultants, engineers, main contractors, and specialist contractors, were interviewed.

The topics mainly covered the issues of the current cladding industry, particularly communication and decision-making. The interviewees typically experienced problems of the barrier of information exchange and the usage of IT. The willingness to use a new communication model, the possibility of third party involvement at the intra-project level, and development of an integrated decision-making mechanism were also discussed. The information gained from these interviews has been summarised and analysed in chapter 6, providing both a foundation for and validation of this research.

4.7.4 Questionnaire

4.7.4.1 The design of the questionnaire

Schutt (1999) argues that a questionnaire is a survey instrument containing the questions in a self-administered survey. A questionnaire approach is widely used for collecting survey information. It can "provide structured and numerical data, which is comparatively straightforward to analyse" (Cohen et al., 2000). It is also considered to be a rapid, relatively easy and inexpensive way of collecting and discovering data on the characteristics and beliefs of the population at large (May, 1993). In order to get industry professionals' opinions of current information sources and decision making systems and their requirements for improvements, questionnaires tend to be more suitable than the other methods.

A pilot questionnaire was created and tested on a small group of colleagues. However, it was found that it was too complicated for general respondents who had not read the background information carefully.

Therefore, a revised questionnaire, gaining valuable information from simple questions, was produced and posted on the CWCT website (with a link on the homepage at http://www.cwct.co.uk) (Appendix D).

The questionnaire was the central feature of this survey process. It included 25 questions and could be divided into four sections: respondents' demographic information, extra-project level information sources, intra-project level communication, and CWCT focused comments. The questionnaire served to develop the conceptual model of integrated communication and decision making, and partly validated the idea.

4.7.4.2 Respondents categories and percentage returns

More than 800 professionals were invited to answer the questionnaire on-line. Some people, who visited the CWCT web site regularly, though outside the mailing list, also responded to the questionnaire. In total 62 valid responses were received. Table 4.1 shows the respondents to the questionnaire, as well as the percentages of returned questionnaires per group of organisations.

Company type	**Number**	**Percent (%)**
Architect	7	11.3
Client	3	4.8
Engineer/consultant	18	29.0
Main contractor	5	8.1
Manufacturer/supplier	12	19.4
Specialist contractor	17	27.4

Table 4.1 Questionnaire responses by company types

4.7.4.3 Analysis

In order to have a deep understanding of the data obtained from the questionnaires, the Statistical Package for the Social Sciences (SPSS) was used to analyse the responses. SPSS is one of the most widely available and powerful statistical software packages. Although the SPSS software can provide sufficient help for the statistical analysis, it cannot be considered to be the only method of analysing quantitative data. Other mental interpretations may also be considered to be effective, particularly as the author has an intensive understanding of the cladding industry and may look for more complex patterns of response.

4.7.5 Other considerations

Reliability and validity of data

The reliability and validity of the responses needed to be tested after the fact to assess the quality of the information obtained (Schutt, 1999). In this research, the author carefully employed primary data from the questionnaire and interviews. The mixed use of quantitative and qualitative methods and various data collection methods enabled checking of the reliability of the data and the validity of the methodology. On the other hand, most of the respondents of the surveys hold senior positions in the different companies; therefore their in-depth understandings and opinions from various perspectives provided extra validity to the data.

Ethical issue

It is important for researchers to think carefully about research ethics, such as confidentiality of data and respondents' right to privacy and anonymity. Especially, the data collection stage is associated with a range of ethical issues (Saunders et al., 2003). In order to avoid these issues, in the questionnaires and interviews, the author particularly stated that all information would be treated in strict confidentiality and would only be used for this academic purpose.

4.8 Model development and validation

Based on the literature review and preliminary research, a conceptual model of integrated communication and decision-making within the context of the cladding supply chain was proposed. Details of the model are illustrated in chapter 5. It was further developed following the industry survey and interviews.

It is very important to validate the research findings. Some parts of interviews and the questionnaire serve to guide development as well as validate the current conceptual model. A final step of evaluating the functionality and in particular the applicability of the conceptual model was undertaken as described in chapter 7.

4.9 Summary

This chapter has defended the selection of the research method, planning and execution of the research. The research adopted both deductive, and to a lesser extent, inductive approaches to develop a communication and decision-making framework; and employed a mix of qualitative and quantitative methods for the data collection and research validation.

Chapter 5 Initial Model Development

5.1 Introduction

This preliminary stage of the research is exploratory, based on the literature review and observation of the cladding industry. In the beginning of the research, some initial ideas were proposed and implemented, including; development of an IT platform for communication in projects on the basis of the work of Ledbetter (2004a) and comparing the cladding industry with other industrial sectors that are perceived to perform better, especially the automotive industry. However, it was found that information sources would be difficult to identify in practice, and therefore a conceptual integrated communication and decision-making model would be proposed with a higher level of understanding. This could lead to the development of a formal and functional IT platform.

5.2 Software development

5.2.1 Introduction

As described in chapter 3, Ledbetter (2004a) initiated on-line software for communication during the process of cladding procurement. The author continued to program the software in perl, and MySQL was adopted as database tool in the development.

The aim of the software is to facilitate collaborative design and procurement in facade projects, and initial development of the software focussed on setting up fixed databases bespoke to a particular project. This software enables a project co-ordinator to set up and manage databases for a particular project, and assign rights to decision-makers from different parties who will have appropriate access to view and/or edit the project data.

5.2.2 The software

The software is a web-based collaborative communication and decision making support package. For a specific building procurement project, the most important function of the software is to collect and classify all information from all aspects at different stages, and then distribute the appropriate information to appropriate parties.

The software was programmed in perl, and MySQL was adopted as a database tool in the development. The website and databases were operated on the Bath University's servers, and the main scripts and webpage are shown in Appendices A and B.

Initial development of the software focused on establishing fixed databases bespoke to a particular project. It was necessary to have a data manager to configure the databases. Therefore, the software has a manager interface and a user interface for the data manager and users respectively, which enable a data manager or management group to run more than one project simultaneously.

For a specific project, a data manager needs to set up databases of access permission and project information according to the features of the project. The database of access permission assigns participants write access and read access to relevant information. These permissions could be assigned on the basis of a standard form of contract such as JCT or FIDIC, or could be bespoke. Project data could be in different formats which include logic, numerical, formatted numerical and descriptive data, and all data needs to be tagged to identify the nature of the piece of information and the part of the facade to which it applies. To facilitate this it is necessary to split the facade information into zones matching the commercial packages used to procure the facade from separate specialist sub-contractors. However, the software could be further extended to zone the package interfaces separately from the principal facade zones.

After the appropriate databases have been established, the participants of the project, who are the users of the software, can follow the process shown in Figure 5.1, to gain access to relevant information and edit the information/decisions they are responsible for online.

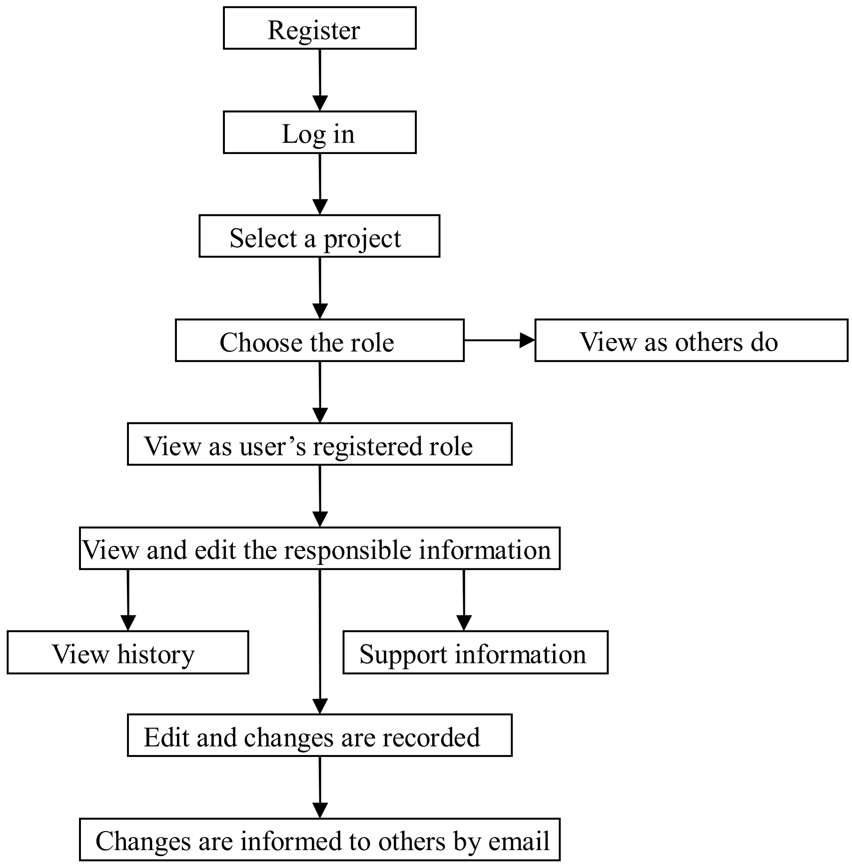


Figure 5.1 Process flow of using the software

A user needs to be enrolled by a data manager or register himself with a particular role in the project through the link on the homepage (Figure 1 in Appendix B). Then the user can log in and select a project he is working on (Figure 2 in Appendix B). After this, the user needs to select a viewing role (Figure 3 in Appendix B). This option is provided so that a user may either view information intended for them, or view information seen by another party. For instance the main contractor may wish to be viewing the same screen as the specialist sub-contractor whilst talking over the phone or simply to check that the specialist contractor will see the appropriate information. If the selected role is not his registered/genuine role, this user can see another party's responsibilities of information supply but can not edit any data. Only if the user selects his registered role can he have write access to the information he is responsible for (Figure 4 and 5 in Appendix B).

Every data item that appears on a user screen has buttons labelled 'more' and 'history', which give the user pop-up windows containing the technical support information and records of previous changes respectively. A decision slot can only be filled and changed by the responsible party who has the edit authority. Each item of data is tagged with the name of the provider and the time/date, every time that it is edited, which make all decisions and changes fully traceable.

When the user supplies new information or edits previous data and clicks the button of 'update', the changes will be recorded as an entry in 'history' and informed to others automatically by email.

5.2.3 The issue: sources of information

The development of the software explored the technical feasibility of the web-based communication tool for cladding procurement, especially from an IT perspective. It focussed on setting up databases bespoke to a particular project, and the access rights of viewing and editing information for different parties were set up by the within the software.

However, in a real case, the source of data would be difficult to identify. For example, the windload information in the database could have various information providers on different projects. There must be a competent coordinator to organise the process and indentify the responsibilities for information provision project by project, even if there is a general guideline.

There is also difficulty in managing and interpreting data. Windload data for cladding is different from that used for design of the structured frame. Information provided by a structural engineer may not be relevant to a cladding designer.

5.3 Comparison with automotive industry

Due to the difficulties of identifying and interpreting information sources, the on-line software can not be a one-stop solution for integrating decision-making and communication. Investigation was undertaken into some other industries which have a good reputation on supply chain management and ICT integration, like the automotive industry as discussed in section 3.8.

Both the automotive and construction industries have multi-tier hierarchies of supply net, but it is obvious that e-hubs are playing fundamental roles in the modern automotive supply chain and business to business (B2B) relationships. Ideally, an e-hub should be able to serve both price-based market networks and collaborative-based knowledge networks. But in practice, industry level e-hubs only emphasise one of them. In the automotive industry, most e-hubs work as an e-marketplace for the exchange of goods.

Comparing the construction industry with other modern industries, the distinctive feature of the construction industry is that its production is one-off. Therefore, there is a greater need for a hub that is project focussed and knowledge based to be an information and communication centre integrating parties and processes in particular projects. There is still a role for an e-marketplace for selling and purchasing materials and components; however, this should be separate and independent of the knowledge base.

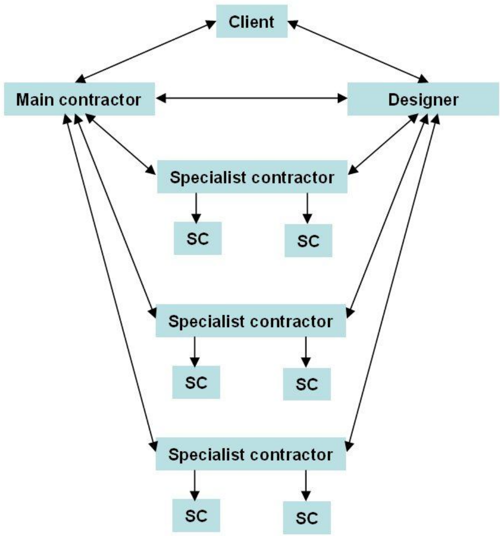
Lessons gained from the literature review show that e-hubs run by a group of non-competing firms or one non-trading firm work relatively effectively in the automotive industry. That means there is an opportunity for a third party to play this role. Also, a third party can be an independent force to configure an inter-organisational information system and indentify the primary extra-project information sources for the cladding supply chain.

In the construction industry, especially the cladding sector, there are no players who can play a dominant role in the supply chain, unlike large vehicle makers which can lead the automotive supply chain at industry level. Therefore, an industry supported third party would be appropriate to fill a similar role, but matched to the industry's own characteristics and demands.

5.4 A conceptual model for integrated communication and decision-making

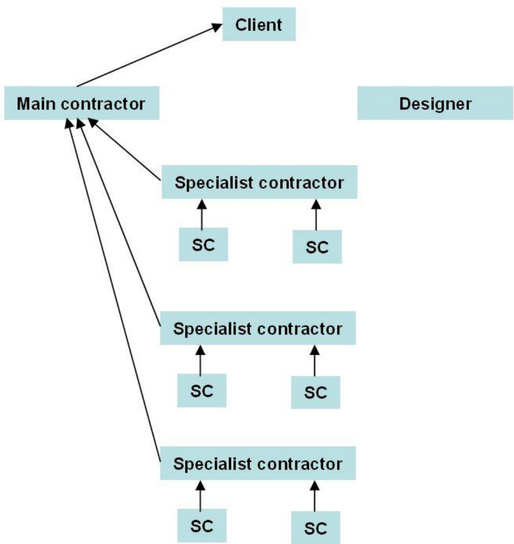
5.4.1 Introduction

The current cladding supply chain is structured as a complicated hierarchy with several tiers of suppliers within the chain, where lower level suppliers provide materials to the next level of suppliers. There are many different types of companies all with different objectives, skills and aspirations (Connaughton et al., 1994); these include building clients, designers, main contractors, specialist contractors, sub-contractors and suppliers. The basic flows of product, information and funds are shown in Figure 5.2.



SC = sub-contractor

Figure 5.2(a) Flow of information



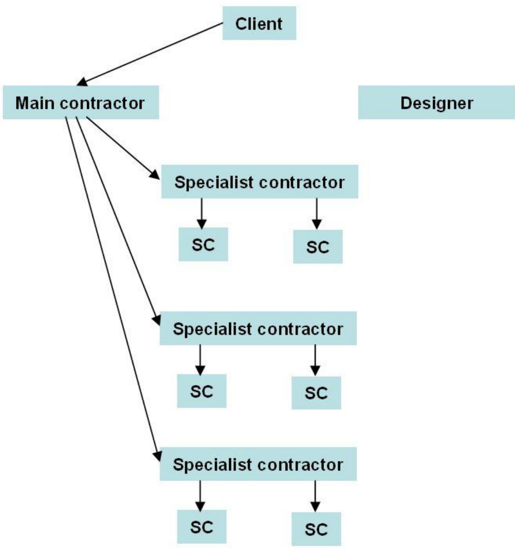


Figure 5.2(b) Flow of product

Figure 5.2(c) Flow of funds

Basic sub-contractors are simply instructed what to do by the provision of a prescriptive specification and drawings, in which case Figure 5.2 is a good indication of the complexity of the flow of information.

The use of specialist contractors who design, manufacture and construct facades is necessary for the realisation of advanced facades as the building designers (architects and engineers) do not have in-depth knowledge of the manufacturing and construction techniques available.

However, the use of specialist contractors further complicates the flows of information. Specialist contractors responsible for adjacent work packages have to detail and construct interfaces and this requires the exchange of information between specialist contractors. Interfaces may be between different cladding packages, cladding elements or between the cladding and the building structure or services. The complexity of these interfaces and the associated design processes are described by Pavitt (2002).

The flow of information between specialist contractors may be direct, Figure 5.3(a) or through the main contractor, Figure 5.3(b).

Direct communication between specialist contractors has the disadvantage that the main contractor may not be aware of the decisions made. It is also the case that specialist contractors are not normally required by their contracts to supply information to other specialist contractors and that they do not wish to incur design responsibility for interfaces or adjacent works.

Main contractors have experimented with the appointment of a principal, or lead, specialist contractor so that the flows of information are those shown in Figure 5.3(c). However, very few specialist contractors are able or willing to take on the role of principal specialist contractor. This approach is still used for simple interfaces such as roof lights into roofing or windows into holes in walls.

In the UK the introduction of whole building air leakage testing placed great emphasis on the quality of design and construction of building envelope interfaces. Most main contractors now bring together specialist contractors to ensure adequate exchange of information and to ensure that adjacent cladding details are coordinated, Figure 5.3(b). The persons undertaking this work within the main contractor may be called ‘Cladding package manager’, ‘Design coordinator’ or some other similar title. On the Vodafone Headquarters building in Newbury, UK, there were 14 separate cladding packages. Whilst no single cladding package interfaces with all the other 13 the number of different interfaces is large and it can be seen how complex the process of design coordination has become.

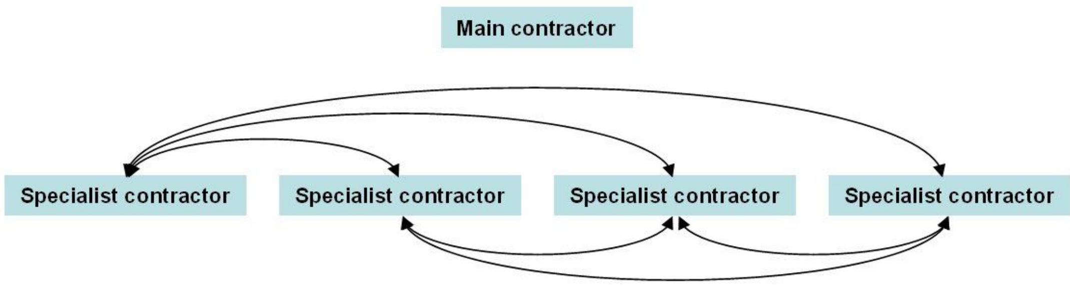


Figure 5.3(a) Direct communication between specialist contractors

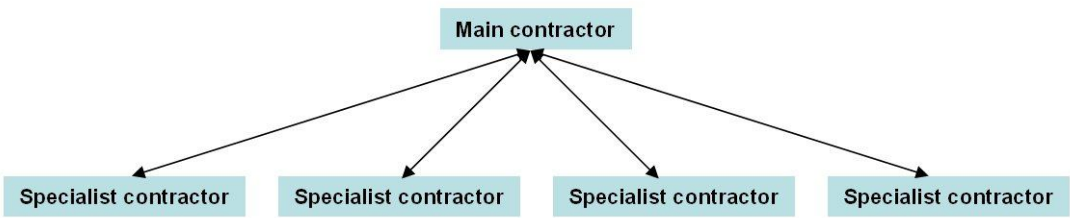


Figure 5.3(b) Communication through main contractor

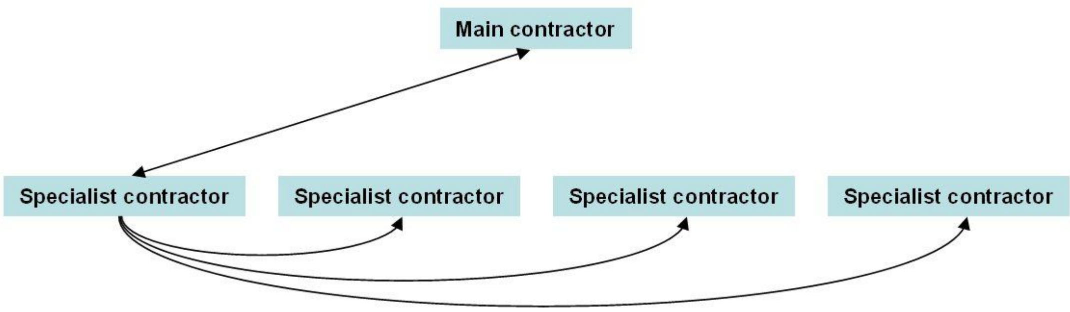


Figure 5.3(c) Communication through a principal specialist contractor

The complexity of information flows is not only complicated by the number of specialist contractors but also by the different forms that specialist contractors may take, in particular the large number of separate companies that may be involved in the specialist contracting process for any single cladding package.

The specialist contracting process may be divided into discrete sub-processes of:

- System and component design
- System and component manufacture
- Project design
- Fabrication
- Installation

Ledbetter (2001b) describes how these sub-processes may be undertaken by a single company or separate companies. The different structures for these companies have been shown in Figure 3.11.

The use of performance specification and specialist contractors implies that decision making is passed down to the specialist contractor. However, some design decisions may be taken at a level below the specialist contractor. The specialist contractor will procure many of the façade materials and components from suppliers. This will include the supply of glass, infill panels, fixings, hardware, fire stops, blinds, shading devices and so on, Figure 5.4.

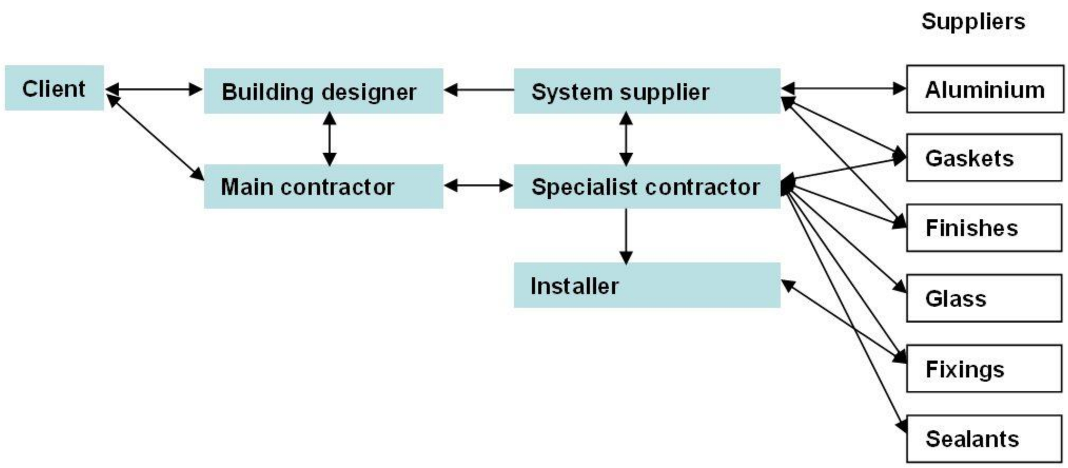


Figure 5.4 The players in the cladding supply chain

Very often the specialist contractor relies on the supplier for advice on the performance and suitability of materials and products. The quality and relevance of any advice given is totally dependent on the quality and extent of information passed to the supplier at the time the advice is requested.

The supply chain therefore becomes deep and is heavily dependent on the proper flow of information to ensure an appropriate flow of 'goods'.

In the case of glass supply, Figure 5.5, the supply chain extends down over five levels from the building designer to the glass supplier. The glass supplier understands and advises on; environmental coating performance, self-cleaning coatings, U-values, g-values, light transmission, impact resistance and so on. However, it is not at all certain that adequate information flows far enough down the supply chain to properly inform this decision making. Information such as required service life, service environment and all of the required performance characteristics may have been corrupted or lost in the long communication chain.

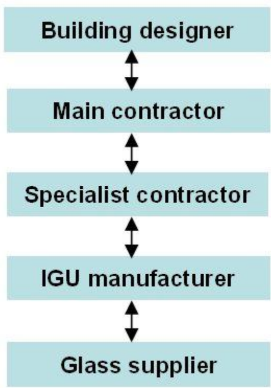


Figure 5.5 Glazing supply chain

5.4.2 A conceptual model

An initial idea to get around the problem of the intertwining flows of goods, finance and knowledge/instructions is to make the communication network relatively independent of the supply chain. Based on this idea, a conceptual Integrated Communication and Decision-making Model (ICDM) is proposed.

In this model the most significant feature is that a 'third party' is incorporated as a new player alongside the supply chain to work as an Information and Communication (I&C) Hub, Figure 5.6.

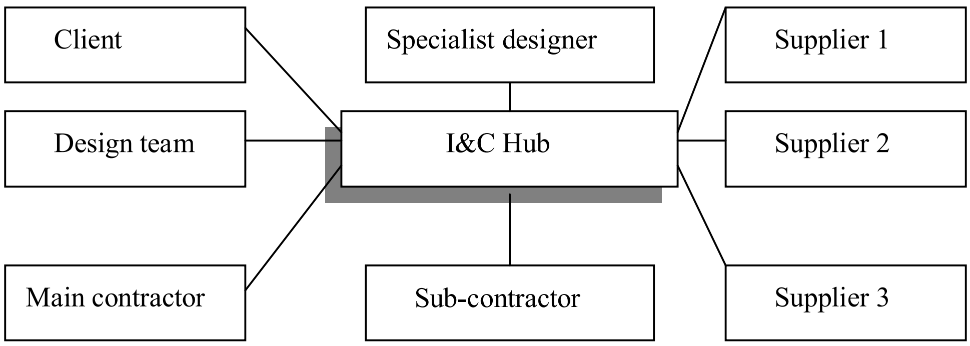


Figure 5.6 The simplified independent communication net

The I&C hub radiates channels, connecting with every original member of the process and formalising the routes for the information flow in a supply chain. The simplified independent communication network, shown as Figure 5.6, implies the information hub will act as the pivotal part in the information exchange process. The information technology, which was reviewed in section 3.7, could facilitate the exchange process from a technical perspective.

All information flows into the hub and resides in an appropriate position where the members in the communication net can access certain areas. When any members need information, they just need ask for it from the information hub directly instead of other members who may only have unilateral or partial information. Even if the original communication routes are still used for backup in the preliminary stage, the independent communication network can be operated in parallel. Information flow would therefore be secured, integrated and used to facilitate decision making.

Reform of the communication mechanism may make the decision-making process a real interactive process, making decision-making easier, quicker, and more reliable.

5.4.3 Operation mechanism

The central part of the ICDM is the I&C hub, the information pivot of the independent communication net. It would have the ability to collect and process all necessary information from responsible parties, and provide the appropriate information to everybody involved in procurement on the project. On the other hand, it should be an interactive system, which permits individuals or organisations to contribute information, track latest decisions and query decisions made by other parties in a project at any moment. When it is developed, this hub could offer active assistance in details, such as advice to installers on a work programme in the light of a weather forecast.

As we know, mainly because of the increased complexity of walls and the wide range of building solutions, performance specification has replaced prescriptive specification in many aspects. For example, in the case of facade design and construction, prescriptive specification requires in-depth knowledge of materials and detailing of curtain walling that is not always available to architectural designers and specifiers. Performance specification allows architectural designers to specify at their level of knowledge the required performance of the wall and to pass responsibility for detailed design to the specialist contractor. It is thought that performance specification can lead to good and economical design and construction by drawing on the specialist contractor's skills, and it can also mitigate partly the conflict between architects and manufacturers.

However, the performance specification has to be translated to a prescriptive format in the end to aid manufacture and installation, mainly by specialist facade contractors or cladding designers, who have to be prescriptive in the ordering of components and materials. A point to be noted here is that the process of this “translation” is also an interactive process that all members take part in and contribute to. This requires that the proposed information hub must be an interactive communication centre to achieve the interactive specification. In addition, if any change is required during the construction stage, optimised solutions would be produced promptly under effective collaborative work.

To realize the functions described above, an interactive database and an information manager or management group are necessary. In other words, an interactive information hub needs database software and people who support and run it.

5.4.4 Managing the I&C Hub

5.4.4.1 The nature of the hub

In practise, some information may apply to more than one project, and some information is specific to a single project. Thus, the information relevant to a project should be separated into two levels: intra-project information and extra-project information.

According to the two kinds of information, the I&C Hub for the independent communication net needs to be set up as a two-level hub, which includes intra-project level and extra-project level information, Figure 5.7.

At the intra-project level, all participants in a particular project would submit the necessary information that they have and decisions that they have made, and ‘pick up’ the appropriate information that they need access to when making further decisions. The information exchanged at this level includes project information details, such as the building design life, construction environments and component specific information.

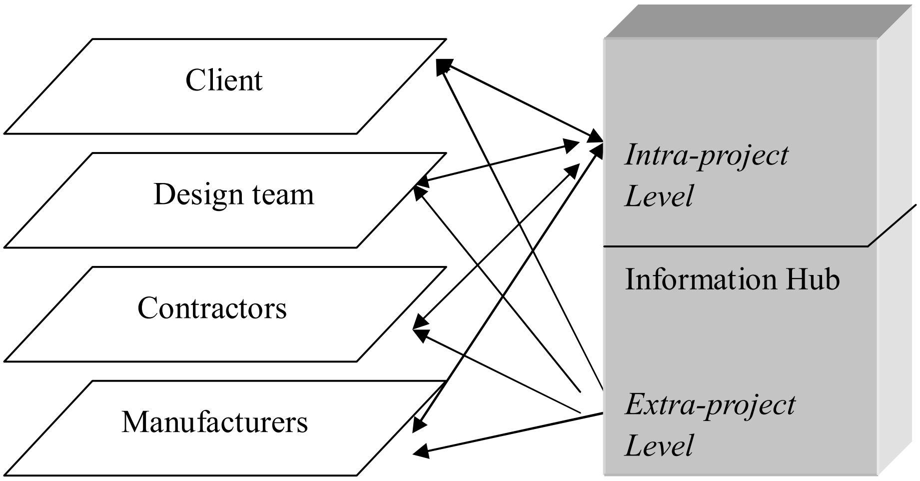


Figure 5.7 A two-level I&C Hub

At the extra-project level, general information would be provided by the information hub, including public information, semi-public information and documents such as British Standards, Building Regulations and other specific standards or guidance. Participants in a project usually only receive appropriate information but do not need to contribute at this level. Some extra-project level information may be hosted elsewhere and linked from the information hub, for instance, National Standards.

5.4.4.2 The competent third party

It has been identified that a third party may act as the information and communication hub, but who is qualified to set up and run the hub? For the cladding supply chain, the hub should be operated by a non-trading firm or one that is not considered a trading partner. This may be necessary due to the sensitive information of trading companies. The necessary qualifications of the third party broadly include facade engineering expertise, management capacity, IT skills, wide support from the cladding industry, and even educational resources and experience from training sessions. Put simply, the third party should have a broad range of skills and extensive industry contacts.

Therefore, the professional structure and technical capabilities of the third party need to cover the following aspects:

- Procurement process consultation, supply chain management, contract and construction law
- Manufacturing, Installation and materials
- Structure, integrity and testing
- Building physics – thermal, acoustics, lighting, ventilation, etc.
- IT support

The information manager may also have the responsibility of supervising the information programme, with the facility to email hub members automatically.

To set up the hub, initial funding and facility support from a government, research organisations or industry would be necessary. When the hub is established and has been proved, the hub could be promoted commercially.

5.5 Information flow and an example of glass selection

In order to better understand how the design/selection process may operate and the application of the ICDM to design/selection, it was decided that a single strand of the supply chain should be studied in more detail. The glass supply chain was selected because:

- It is one of the most complex aspects of facade procurement and a good test of how the ICDM might function;
- It is relatively self-contained within the facade supply process;

- It relates to other aspects of building design, most significantly, the design of building services and requirements for insulation, light transmittance and control of solar transmittance.

Glass is widely used for its properties of transparency. It has been favoured by architects for the last two decades and used to deliver a distinct style of architecture. However, its characteristic of fragility makes safety the prime concern. The potentially conflicting performance requirements, especially in environmental aspects, such as acoustics, condensation, heat loss and solar gain, are also testing the designer's ability.

The participants in the glass supply chain may include the client, cost consultant, design team, facade consultant, main contractor, facade specialist sub-contractor, suppliers and even potentially the building operator, and maintenance contractor. All of them may contribute to the decision-making of glass procurement.

Glass selection will start from the architectural intent and pass through three tiers of consideration, i.e., Emphasised/prior requirements, safety requirements, and environmental control considerations, Figure 5.8.

This hierarchy of decision making exists because security requirements have the highest priority as they are the most restrictive, with the fewest options for glass selection. Considering these aspects first may eliminate particular materials and design solutions.

Strength and safety form the second tier of consideration. They may require particular glass size and thickness, and often determine the type of the glass that has to be used.

Building physics considerations may require a particular glass, for instance an acoustic laminate glass or a particularly thick glass to provide noise attenuation. In general, environmental control may be achieved by glass coatings, which may be applied to most glasses and do not generally limit the glass selection. In the event that a glass solution cannot be achieved it may anyway be possible to use blinds or a shading device.

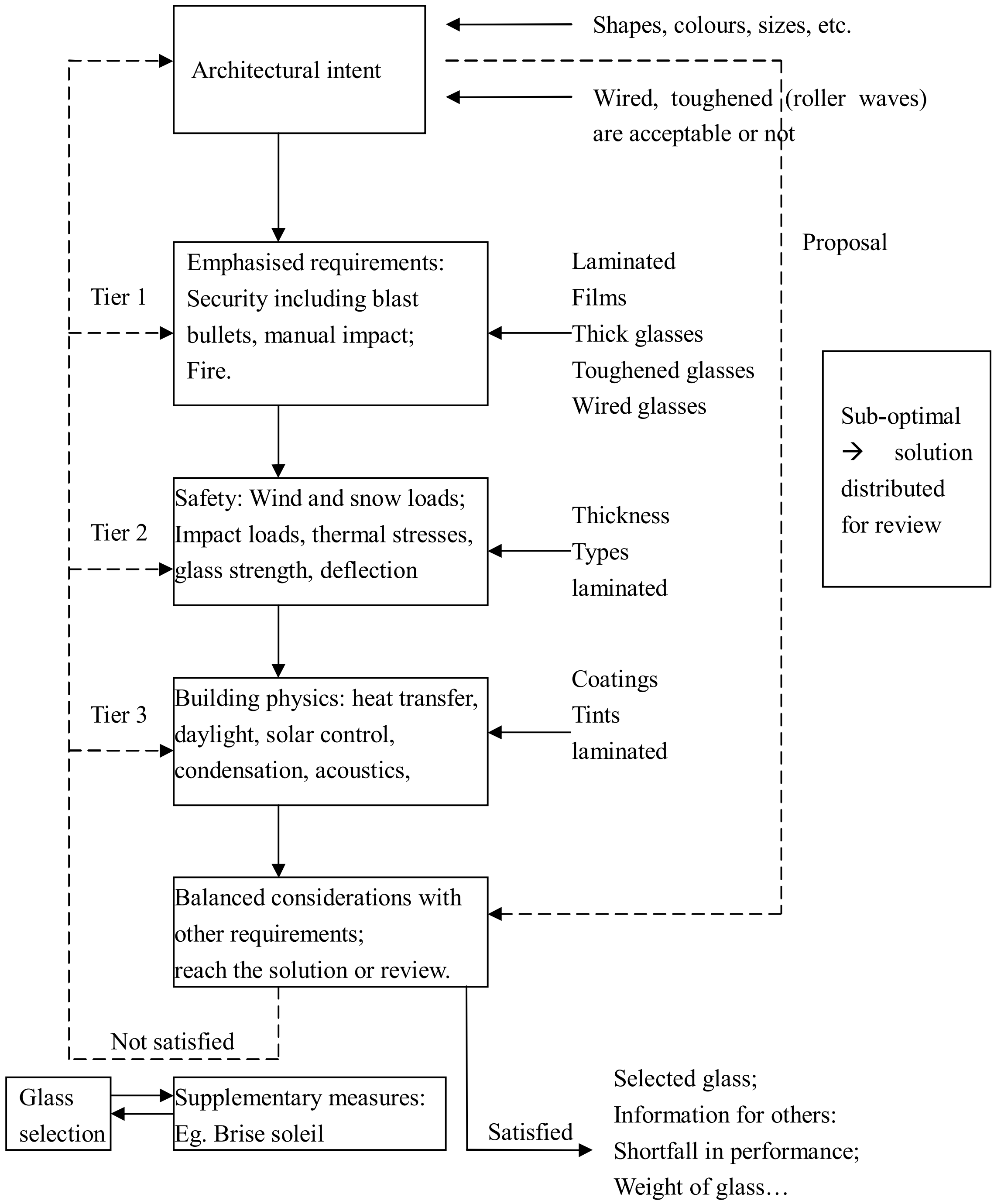


Figure 5.8 A hierarchy of decision making on glass selection

However, even this approach may lead to design conflicts, incompatible requirements and sub-optimal design. For example, both security glazing and high acoustic performance could be required by the specification. Laminated glass may be used to improve acoustic performance, but acoustic laminated interlayers are often made of a formulated resin that does not provide the same degree of safety performance as PVB glass. Under this circumstance, a number of solutions could be considered: 1) bespoke three-layer single glass; 2) double glazing with acoustic interlayer and security interlayer in two panes respectively; 3) using film backed acoustic glass. In addition, security glazing may hinder the means of escape in an emergency, such as fire, and impede forced entry by rescuers. Therefore, it may be necessary to consider alternative approaches to escape or to security, for instance, alarms or CCTV.

After working through the three tiers, the process reaches the summary point to produce a balanced solution, which will be examined against other principles such as costs, lead time and constructability. Some alternative or supplementary measures like brise soleil could be employed to gain enhanced performance. If the solution meets all the requirements, and falls within the resource limits, the glass may be defined and the necessary information passed to relevant parties; if not, sub-optimal solutions will be proposed and a review process will be triggered. This will have to consider which is the 'least worst' solution. A sub-optimal solution could be made in more than one tier. The upper tier will however have higher priority when requirements conflict.

The Review process of sub-optimal solutions may consider the following options:

- Agree sub-optimal performance
- Examine the feedback to non-cladding elements, such as brise soleil.
- Change input information

The solutions can be signed off if all parties agree. However, there are a number of constraints:

- Client information, for example, the colour they desire.
- Regulatory information, including the building regulation and planning requirements.

- Design information, such as wind load, acceptable deflection and safe failure.

Data within the project has different importance and significance. Some can be negotiated with the client; some may require planning amendments; and some like wind load is non-negotiable. Therefore, there are possibilities that a sub-optimal design cannot be adopted if;

- The solution is unacceptable to client;
- There is regulatory infringement;
- There are design inadequacies, especially involving potential risks of security or safety failure.

The tiered approach to selecting glass described above may be applied in terms of technical performance as described in Standards, Norms and test methods. However, glass, like many other elements of the building envelope, is selected to take account of other more subjective factors.

On the more prestigious façade contracts the Client and Architect will require samples of the glass and may visit the glass manufacturer's plant. The purpose of this is to check the appearance of the glazing. The principal factors affecting appearance are flatness, colour and patternation.

Flatness of the glass is often an issue for heat treated glasses (toughened and heat strengthened glasses). European Product Standards for these materials give an allowable lack of flatness in terms of local and overall bow. However, these limits are set to allow the worst glass processors to comply and many glass processors can produce glass that is flatter than that allowed by the Standards. In general flatter glass is produced in better quality plants and costs more than glass that only just meets the requirements of the Standards. Clients place a value on the appearance but how much will they pay for glass of better appearance and how much should they pay.

Colour and patternation may be uniform and well controlled for standard products such as tinted glass. However, colour and patternation are more variable and less uniform for other products including:

- Spandrel glass that is opacified by painting or enamelling one surface
- Glass that is coloured by laminating with a coloured interlayer
- Laminating glass to a thin layer of marble

Acceptance of a particular product on a project will depend on visual inspection and of course cost.

Decisions on which glass processor should be used come down to considerations of:

- Ability to comply with technical Standards
- Quality and appearance of glass
- Availability and delivery times
- Cost

This becomes a balance between cost and quality.

The Client/Architect may specify many things but ultimately the suppliers will respond to tender enquiries with products that may not fully comply with the specification. It may happen that none of the suppliers will fully comply with the initial specification or that a none compliant bid appeals to the Client because the cost is lower. A further complication arises where one glass processor proposes to achieve the specification by processing of the glass by more than one company and a second processor proposes to complete the work in a single plant by one company but not fully meet the requirements of the specification. The compliant product may have a longer and less assured delivery time and the Client may value surety of delivery more than appearance of the glass or even full compliance with the performance specification.

On smaller and simpler projects the materials incorporated in to the building envelope are more likely to be standard products with little doubt about their appearance. It is also less likely that money will be available to purchase glass of higher quality than that typically available. On these projects the decisions on which glass and which glass processor to use are based only on technical compliance and cost.

5.6 Summary

The initial idea was to develop a project-based on-line IT platform to facilitate communication and collaborative decision making; however, it was found that the information sources within and external to the project were difficult to identify. The ability to assign responsibilities for inputting information is critical to the setting up of an IT platform and is a potential weakness of any IT platform.

Clearly, a more comprehensive model is required. Experience and lessons are gathered from other industries especially the automotive industry, which is longer established and better developed on supply chain management. A significant characteristic they have is the concept of an 'e-hub'. However, a unique feature of the construction industry is that every project needs its own design oriented procurement rather than procuring more standardised components directly.

Therefore, a more comprehensive hub is required, which is a knowledge-based and project-focused platform run by a third party. An Information and Communication Hub was proposed and a working mechanism was described, which it is hoped will be able to provide all the information needed and assign the responsibilities for the information provision and decision-making through an expert managed centre.

This hub was the base for further research and a survey was used to test the concept. A questionnaire would be developed mainly based on and for the development of the conceptual model.

Chapter 6 Data Collection and Analysis

6.1 Introduction

Chapter 1 provided the introduction to the thesis explaining the aims, objectives, scope and justification for the research. Chapter 2 descried development of the cladding industry and the background of this research. Chapter 3 reviewed the relevant literature that helped guide the research objectives and defined the gap for this research. Chapter 4 stated the research design and research methods adopted. Chapter 5 illustrated the initial idea and preliminary development on this research, which is summarised by an I&C hub. This chapter presents the data collection and analyses the results.

The data collection, as described in Chapter 4, mainly used a questionnaire circulated in the cladding industry, while industry meetings and interviews were employed prior to the questionnaire survey to discover the realities of the industry and develop the new communication model proposed in Chapter 5.

6.2 Industry meetings

From Spring 2005 to Autumn 2008, the author attended a number of industry meetings and seminars, especially CWCT member meetings, in which speakers and participants came from different industry parties across the supply chain and the author acquired first hand information and gained an holistic understanding of the industry.

Some of the industry conferences and CWCT meetings held at Bath University focused on technical topics, which included:

- Glass in Buildings (2), 7-8 April 2005
- The International Conference on Building Envelope Systems and Technologies (ICBEST 2007), 28-30 March 2007
- Built up Layered and Rendered Cladding System, 1 April 2008
- Sustainable Construction of Large Buildings, 19 September 2008

They were mainly technical topics but there were always differences of opinion. Some of them are technical misunderstandings, simply because of the lack of knowledge or capacity to understand. However, there are divergent opinions on

- Acceptable design and performance
- Industry norms and standards

The reason for this may come from the participants' different background and interests. This phenomenon confirmed the need for better communication between parties and that a practical industry level communication framework is critical.

There were also several recent CWCT meetings that addressed issues on management aspects, as follows:

- The Future of the UK Cladding Industry, 22 September 2005
- Buildings of the Future – Roles and Design Responsibilities, 21 April 2006
- Cladding Complexity as the Norm – Communication, Competences, Costs, September 21 2007

The author was unable to attend the one held in 2005. Therefore, the following is a summary of the opinions presented by different parties at the meetings in 2006 and 2007.

The complexity of building facades

The performance requirements of building facades are rapidly changing and cladding products tend to be increasingly complex.

Meulenberg (2006) indicated there were many aspects of the changing requirements, such as thermal performance, weather proofing, fire performance and sustainability. The enhanced performance comes mainly from function separation and optimisation, which means the future solutions of the building facade need more specific knowledge and more intensive communication in the supply chain. McGuckin (2006) admitted that the technical details were too complicated for a client and stated he could only treat the building facade as a "Big Glass Box". Brunswick (2007) noticed that main contractors had to allocate much resource to resolve the complexity of building facades. Even for a cladding specialist contractor, Bowen (2006), from Parry Bowen Limited, recognised there were too many challenges to face and especially, the facade testing had given him a great pressure.

Issues on interface management and communication in the cladding supply chain

The complexity of the building facades has led to the deepening specialisation of the cladding supply chain. Fragmentation exists in the supply chain and there is a lack of trust between parties. Efficient interface management and communication are important but limited in the facade procurement process.

The industry was generally believed 'volatile' and difficult to partner effectively by the clients (McGuckin, 2006). Harris (2007) indicated that;

- Many sub-contractors were working in isolation, and push the responsibilities to 'others';
- The interfaces could be major contributors to thermal bridging and air leakage and the performance was generally poor;
- There was a lack of integration.

Lord (2006), from CAP, emphasised there was a lack of clarified information and trust in projects. Bowen (2006) expressed a sub-contractor's psychological phases of a project:

1. Enthusiasm,
2. Disillusionment,
3. Panic,
4. Search for the guilty,
5. Punishment of the innocent,
6. Praise and glory for the non-participants.

However, the industry desires collaboration and trust, and there have been some good signs for improvement. McShane and Mckay (2006) stated that a main contractor needed to encourage dialogue, secure the supply chain early, provide support for cladding contractors to grow, and build long term partnering arrangements. McGuckin (2006) also called for collaborative work and better communication, and indicated that early input from a cladding contractor was essential.

The updated UK Building Regulations Part L requires more attention to detail, particularly at interfaces. Accordingly, an integrated standard, the CWCT's Standard for Systemised Building Envelopes, replaced the previous Standards tailored to different system types. "The building envelope is treated as one continuous system which ought to meet the specified requirements overall" (Harris, 2007). These changes will encourage the building facade to be considered as a whole, and therefore, improved communication and integrated decision-making are necessary.

The function of an industry level third party

The increasing complexity of building facades requires more efficient knowledge management and information supply, as well as better communication in the supply chain.

This provides opportunities of rapid growth of the knowledge providers and industry advisors. An industry level third party, the CWCT (a leading information provider and trainer in the field of building envelopes and glazing) is gaining widening support from the industry.

Ledbetter (2007), director of the CWCT, pointed out the members of the CWCT covered all the parties of the supply chain, Figure 6.1, and increased from 242 to 280 during one year. The centre provided a series of services for its members and the industry, including cladding focused research, technical advice, publications and training. In 2007, the centre published Standard for Systemised Building Envelopes, Cladding Training On-Line (CTOL) and a number of Technical Notes. Lord (2006) claimed that the industry needed better training and more competent workforce. In addition, the CWCT website (http://www.cwct.co.uk) had about 7000 visitors and average 140,000 items downloaded monthly.

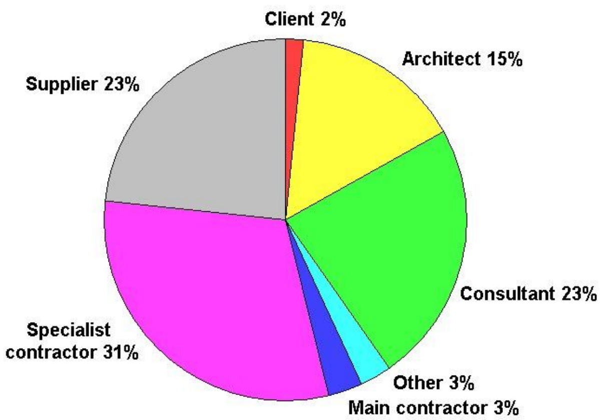


Figure 6.1 The distribution of the CWCT membership (Ledbetter, 2007)

Summary

The different parties of the supply chain may have various perspectives on the industry. However, they commonly recognised close collaboration and better communication are critical to successful facade design and procurement. The means to achieve these could be early involvement of the cladding supply chains as well as cladding contractors, and long term partnering arrangements, though the participants noticed these means often encountered difficulties in practice.

A widely supported industry level third party may have the potential to act as an information centre and provide a communication platform for different parties of the cladding supply chain, especially outside specific projects. In addition, the third party can offer independent training and technical support for the industry.

The understanding gained from the industry meetings informed the following interviews and questionnaire design, and enabled the author to establish a personal network which benefited the further interviews and questionnaire survey.

6.3 Interviews

6.3.1 Introduction

The research was presented in a departmental seminar and three international conferences at different stages. Comments from the industry and academia were received to refine the initial ideas and framework. The author also took an active part in CWCT member meetings, relevant lectures, real projects and conferences, which provided opportunities for the author to set up a wide network and carry out interviews with senior practitioners in the industry.

The initial aim of the interviews was to gain a general understanding of the realities of the cladding industry, especially issues on relationships, communication and decision making in design and procurement. Also, it was hoped to collect valuable suggestions for the development of an integrated decision making mechanism.

34 senior professionals from the following types of organisations were interviewed.

- Architect 2
- Consultant/Engineer 10
- Main contractor 3
- Cladding specialist contractor 11
- Manufacturer/supplier 4
- Test centre 2
- Research institute 2

The basic information of the interviewees is illustrated in Table 6.1:

Position	**Discipline**	**Region**
Partner	Architect	UK
Chief Architect	Architect	Asia
Managing Director Chairman	Consultant Association	UK
Director	Consultant	UK
Director	Consultant	UK
Associate	Consultant	UK
Director	Consultant	Middle East
Associate Director	Consultant	Middle East
Consultant	Consultant	North America
Partner	Consultant	UK
Technical Director	Consultant	UK
Senior Facade Engineer	Consultant	UK
Senior Facade Engineer	Main contractor	UK
Facade Engineer	Main contractor	UK
Senior Planner	Main contractor	UK
Senior engineer	Specialist contractor	Asia
Executive assistant	Specialist contractor	Asia
Vice Chief Engineer	Specialist contractor	Asia
Managing Director	Specialist contractor	UK
Technical Director	Specialist contractor	UK
Technical Director	Specialist contractor	UK
Estimating Manager	Specialist contractor	UK
Technical manager	Specialist contractor	UK
General Manager	Specialist contractor	Asia
Technical Director	Specialist contractor	Asia
Partner	Specialist contractor	Middle East
Asst. General Manager	Manufacturer	Middle East
Commercial Manager	Manufacturer	Middle East
Marketing Manager	Manufacturer	Europe
Account Manager	Manufacturer	Asia
Chief expert	Test centre	Asia
President	Testing & Consulting	Middle East
Senior Research Officer	Research Institute	North America
Lecturer	Research institute	UK

Table 6.1 Basic information of the interviewees

To gain the real opinions from the practitioners in the industry, most interviews were conducted as an informal conversation but actually were semi-structured around the following concerns and sub-topics:

1 Current industry situation and need for improvement

- The complexity and importance of cladding systems and materials supply chains
- The current cladding supply chain
- The inter-organisational relationships and communication
- The need for improvement of communication and decision-making mechanisms
- Strategies for improvement

2 ICT usage and Third-party involvement: acceptance and forms

- Current usage of ICT in the construction industry.
- Project-based IT platforms
- Third party management of IT platforms

3 Suggestions on development of an integrated decision-making mechanism

- The importance and issues of communication
- The importance and issues of knowledge management
- Practical strategies for integrated decision-making
- How can it attract support from the industry

6.3.2 Current situation and the need for improvement

The cladding industry develops fast and new technologies are widely applied in building envelope systems. An architect commented "there are so many new walling systems and materials turning up and it is impossible for us to understand them all. There is a knowledge gap. We often invite facade consultants to help us. But even so, I still notice the failures of facades, such as water leakage and cold bridging, occur at a high frequency, especially at the interface between two subcontractors' work." This means there are still many things to do for the improvement of building facades.

Collaborative design and procurement have become necessary but issues still exist. A main contractor pointed out "We don't have resources to design and produce cladding. It has become really complex, so we often work with our cladding subcontractor when we bid". But the collaboration does not always work well, because the trust has not been set up. "Some cladding contractors often want to push their responsibility to us and do not do their best until they secure the job." On the other side of the contract one cladding specialist contractor's perspective was, "I have to say, many main contractors just 'buy' facades from subcontractors like equipment from a manufacturer, rather than procure it as an organic part of the whole building. It is really wrong but it happens quite often." "We are on their list of 'preferred suppliers', but in fact, they only want the cheapest price."

For different cladding specialist contractors, the materials and technical recourses vary dramatically. One medium size subcontractor said "we only buy systems from Schuco and Kawneer (major system suppliers), and they will provide technical support and training"; while a technical director from the UK operation of an overseas company told the author "we import almost everything from Asia, including design and materials. Reduced costs make us competitive. But we have to train our Asian design staff to understand the British Standards properly. To reduce risk and on-site labour costs, we currently only pick up jobs with 'unitised curtain walling systems'." This means even the same type of companies may have very different operation styles and therefore diverse demands on information.

The communication and collaboration between project participants is often affected by their opposite interests. As a consultant indicated, "Cladding contractors sometimes intentionally cover up or ignore the potential failure risks, even if they notice them. Because it is difficult to identify who should pay for design amendments." A main contractor admitted, "As a contractor, we only do the tasks required. We are far away from real collaboration though we do have a so-called 'partnering programme'. Even if we can suggest better solutions; we don't input extra effort without extra payment. This causes considerable waste, a lot people know, but no one will stand up to change this situation."

All interviewees agreed that good inter-organisational communication is vital for successful decision making, but there is a lack of a standardised process and a mechanism for this. When the author introduced the idea of integrated communication and decision-making (ICDM), the majority recognised it as a good system but added that "we do need appropriate people to implement it".

6.3.3 ICT and Third-party involvement: acceptance and forms

On the topic of the usage of ICT, the majority responded that it has dramatically changed the industry and they enjoyed the convenience brought by ICT. However, concerns were raised about project-based IT platforms. Comments included:

> "We currently use email for data exchange. It is definitely better to have an IT platform to share information automatically. But I have no experience of using inter-organisational project-based platforms. I am afraid it is difficult to indentify the responsibility to provide online information."
>
> "There are several questions. Who will set up and run it? If it needs to be paid for, who will pay and how? I haven't seen a successful case in this industry. There should be a group of people who maintain and update it properly."
>
> "It is lovely, but I have little time and patience to sit down and input the data in an internet cafe. And I will be uncomfortable with the faceless environment."

For the proposal of an independent third party involvement in specific projects, the responses were diverse. Some consultants doubted the feasibility, and they had concerns about the new competitor. Respondents from other groups generally accepted this new framework and agreed with the positive effects brought about by about by the third party, but they were concerned about the additional costs. Comments included:

"If the third party is sufficiently competent, you or your company would like to join the community to share the knowledge in the extra-project level, and use the facility to communicate in the project." (Main contractor)

"We do welcome a new source for facade knowledge and information. But we hope it is free. Because we have paid the facade consultant for this and don't want to pay extra."(Architect)

"I think we have been playing the role of the third party. We coordinate the client, architects, contractors and suppliers. We provide professional services, including detailed design, structural and thermal calculation, system testing, on-site checking and so on. Even some well known manufacturers ask us to design systems for them. We can offer anything our clients want." (Consultant)

"We can't afford an R&D department, but we see CWCT as our R&D. Reasonable payment for these services is acceptable if it is good value for money."(Cladding specialist contractor)

6.3.4 Suggestions on development of integrated decision-making mechanism

When the author asked for suggestions on developing an integrated decision making mechanism, the interviewees provided a wide range of advice, including:

"I believe we need a framework to identify the people who have the most appropriate status and knowledge to be the responsible decision maker."

"The most important thing is an action standard which participants can follow. But who would have the authority and resources to do it? It must be supported by the industry."

"There should be a proper business model for this development. Otherwise, it won't last long."

"A well-managed knowledge database would help this system."

"We need decision makers who have general knowledge on facades so that we can speak in a common language. The third party may contribute more in the training, including training for potential decision makers from different parties."

"If you want to develop an interactive IT platform, you probably have to attract the user with some incentive system. It would encourage interaction and contributions from individuals and companies."

To sum up, there should be a systematic mechanism with a set of essential elements and a team of competent experts to maintain and develop it. The essential elements may include interactive knowledge databases, process protocols of communication and decision-making, a training and education programme, a sustainable business model and incentive systems. The expertises of the management team should have all aspects of knowledge of facade engineering and other necessary skills such as IT.

6.3.5 Summary

The findings of the interviews can be summarised as:

The cladding systems and materials are becoming more and more complex, and the knowledge gap is widening. Therefore, inter-organisation collaboration on facade design and procurement are necessary. However, adversarial attitudes exist between parties with different interests, and the inter-organisational communication in the facade design and procurement is flawed. This seriously impacts on informed decision-making. There is a need for improvement of the communication and decision making mechanisms.

ICT has been widely accepted and used as an important tool in the construction industry. However, most people think we have not made the best use of it. Some organisations have used internal IT platforms for sharing documents and information. However, there is a lack of an inter-organisational communication and decision making platform in this industry, mainly because there is no dominant player which has the resources and authority to set up and run it properly. A third party with high level independency and industry support can probably do it, but the working mechanism and the business model have to be considered carefully.

An integrated decision-making mechanism cannot be realised without efficient communication. A well-designed and managed web-based communication platform would facilitate knowledge management and communication, and enhance the decision making process. In addition, essential elements, such as standardisation, designated decision making groups, training, industry support, an incentive system and so on, should be included in the framework.

There are also a number of barriers to use an I&C hub provided by an independent third party

- Competence of the third party:
    - independency,
    - technical and financial resources,
    - industry support;
- Industry culture and the custom of practitioners;
- Costs and untested prospects for participants;
- Some consultants may hold a conservative attitude.

6.4 Questionnaire

6.4.1 Introduction

After gaining an understanding of the reality of the cladding industry by meetings and interviews, a questionnaire to the industry was produced. The intention of the questionnaire was to validate the concept of a communication model and provide a direction for further development if appropriate.

A pilot questionnaire was initially created and tested by a small group of colleagues. However, it was found that it was too complicated for general respondents unless they read the background information carefully.

Therefore, a revised questionnaire was produced and posted on the CWCT website (with a link on homepage at http://www.cwct.co.uk), see Appendix D.

The questionnaire comprised 25 questions, which could be divided into 4 sections:

- Respondents' background Questions 1-4
- Extra-project level Questions 5-17
- Intra-project level Questions 18-21
- CWCT focus Questions 22-25

The first part contains the respondents' demographic information, including name, and profession and company information. The second part is to collect the respondents' opinions on general information sourcing and communication process, which are related to the extra-project level of an IT platform. The third part further examines the participants' experience of information sourcing on a project. The fourth section is to examine industry's appraisal and further expectation on the performance of an industry level third party – CWCT, especially on its website and Technical Notes.

Questions 9, 20, 22 and 24 used a five level rating as the response system for the answers. To enable analysis of the questions it was necessary to assign a number to the response. Therefore, when the mean and mode are being discussed using a numerical reference it is referring to the system in Table 6.2.

Numerical reference	Question 9 and 20	Question 22 and 24
0	Missing value	Missing value
1	Rarely	Poor
2	Seldom	Below average
3	Occasionally	Average
4	Sometimes	Good
5	Often	Very good

Table 6.2 Numerical code and its referring

For others questions, a single tick box was used. If this option was selected or answered 'yes' by a respondent, its value is assigned as 1 in the tables of Descriptive Statistics, otherwise, its value is assigned as 2. Therefore, if the mean value of the results is lower than 1.5, a majority of respondents agreed with this option.

6.4.2 Questionnaire respondents

869 people from a CWCT mailing list and the author's personal contacts were invited to answer these questions on the CWCT web site. Some people on the mailing list might have left the registered companies but at the same time, some people who visited the CWCT web site regularly, though outside the mailing list, also responded to the questionnaire.

Thus, 62 valid feedbacks were received. Table 6.3 shows the respondents to the questionnaire, as well as the percentages of returned questionnaires per group of organisations.

Company type	Frequency	Percent (%)
Architect	7	11.3
Client	3	4.8
Engineer/consultant	18	29.0
Main contractor	5	8.1
Manufacturer/supplier	12	19.4
Specialist contractor	17	27.4

Table 6.3 Questionnaire responses by company types

Because most professionals on the CWCT's mailing list and the author's industry contacts come from consultants, cladding specialist contractors and manufacturers/suppliers, there is a tendency that these three groups of respondents are represented more than the other three types. Therefore, grouping analysis will be carried on most questions to provide objective results.

The positions of the respondents include project coordinator, technical manager, Chairman, head of structural department, principal engineer, architect, procurement manager and so on. 34 percent of the respondents claimed that they worked for member organisations of CWCT. By regions, the percentages of respondents are illustrated in Figure 6.2.

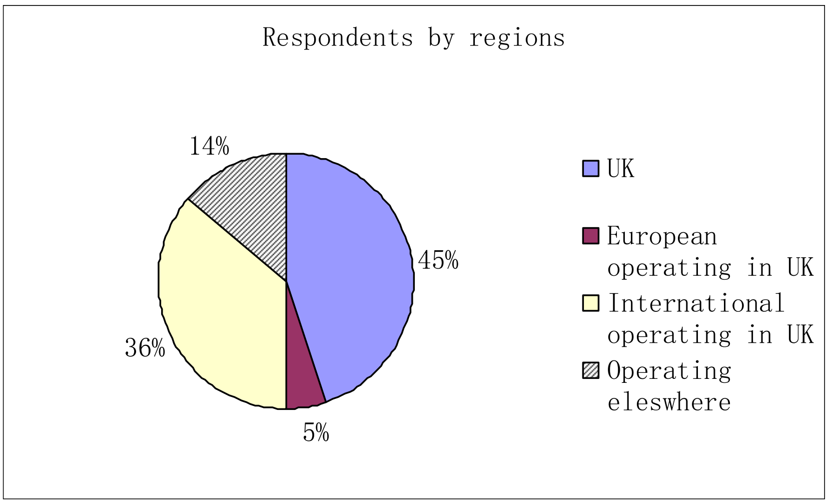


Figure 6.2 Respondents by regions

Many respondents left the reply of 'companies size' blank, but from the limited answers, it can be seen the turnover of their companies range from £200k to £3 billion, and number of employees from 1 to 5,700 worldwide,

6.4.3 Extra-project level (Questions 5-17)

6.4.3.1 In-house resources (Question 5)

Question 5 Which of the following in-house resources are available to you?

Table 6.4 shows the overall descriptive statistical results for the five types of in-house information resources. Table 6.5 shows the differing results between six professional groups. The detailed results for the five resources are included in Appendix E.

Descriptive Statistics: in-house resources

	Library:	Intranet:	In-house:	Project manager:	Line manager:
Valid	61	61	61	61	61
Missing	1	1	1	1	1
Mean	1.31	1.44	1.31	1.49	1.57

Table 6.4 Descriptive Statistics: in-house resources

Company type	Company Library		Company Intranet		In house Specialist		Project manager		Line manager	
	f	%	f	%	f	%	f	%	f	%
Architect	4	57.1	4	57.1	6	85.7	3	42.9	4	57.1
Client	2	66.7	3	100	1	33.3	0	0	2	66.7
Engineer/consultant	18	100	12	66.7	10	55.6	6	33.3	18	100
Main contractor	0	0	2	40	5	100	2	40	0	0
Manufacturer/supplier	10	83.3	7	58.3	9	75	7	58.3	10	83.3
Specialist contractor	8	47.1	9	52.9	11	64.7	8	50.0	8	47.1
Total	42	67.7	34	54.8	42	67.7	31	50.0	26	41.9

(f – Frequency)

Table 6.5 Distribution of available in-house resources

The results show company libraries and in-house specialists are the most available in-house resources to respondents, with the mean at 1.31. However, comparing with 100 percent of the engineers/consultants, only 47.1 percent of the cladding specialist contractors have access to a company library; all the main contractors have in-house specialists but only one third of the clients have. This means there is a big difference of in-house resources between participants in the supply chain. The absence of reference to line manager may simply reflect the seniority of the respondents. The lack of main contractor company libraries or access to them reflects the temporary nature of construction sites and importance of other sources. In general, the results indicate that many respondents have very limited in-house resources.

6.4.3.2 Facade knowledge network (Question 6-8)

Questions 6 to 8 are designed to examine the facade knowledge network inside companies. Question 6 is to discover the proportion of the companies which have a facade knowledge network, and Question 7 and Question 8 further explore whether it is a formal network and means of access to the network respectively. It was assumed that a specialist cladding company should have a good internal knowledge network, so respondents from specialist contractors were asked to skip questions 6 to 8.

Question 6 (If you are a specialist cladding company go to question 9).Is there a facade knowledge network in your company?

Descriptive Statistics: Façade network

Valid	45
Missing	17
Mean	1.40

Table 6.6 Descriptive Statistics: Façade knowledge network

Façade knowledge network

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	4	57.1	3	42.9
	Client	0	0	3	100
	Engineer/consultant	13	72.2	5	27.8
	Main contractor	5	100	0	0
	Manufacturer/supplier	5	41.7	7	58.3
	Specialist contractor	N/A	N/A	N/A	N/A
	Total	27	60	18	40

(N/A – not applicable)

Table 6.7 Facade knowledge network results

Question 7 (If you answered yes to question 6.) Is this a formal network?

Descriptive Statistics : Formal network

Valid	27
Missing	1
Mean	1.19

Table 6.8 Descriptive Statistics: Formal network

Formal network

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	3	75	1	25
	Client	N/A	N/A	N/A	N/A
	Engineer/consultant	13	100	0	0
	Main contractor	3	60	2	40
	Manufacturer/supplier	3	41.7	2	58.3
	Specialist contractor	N/A	N/A	N/A	N/A
	Total	21	80.8	5	19.2

Table 6.9 Formal network results

Question 8 (If you answered yes to question 6.) How do you normally access this network?

Company type	By intranet		By e-mail		Face to face	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Architect	2	50.0	4	100	2	50.0
Client	N/A	N/A	N/A	N/A	N/A	N/A
Engineer/consultant	6	46.2	2	15.4	5	38.5
Main contractor	3	60.0	2	40	0	0
Manufacturer/supplier	0	0	5	100	0	0
Specialist contractor	N/A	N/A	N/A	N/A	N/A	N/A
Total	11	35.4	13	41.9	7	22.6

Table 6.10 Means of access to facade knowledge network

Table 6.6 and table 6.7 show the statistical results for the facade knowledge network in respondents' companies. Tables 6.8 – 6.9 show how many of the networks are formal, while Table 6.10 shows the means of access to a facade knowledge network.

From Tables 6.6 – 6.7, only 60 percent of the respondents have an intra-company facade knowledge network, while all the clients and nearly half manufacturers/suppliers and architects do not have. Tables 6.8 – 6.9 indicate 80 percent of the networks are formal, which means 48 percent of the respondents in total have a formal intra-company facade knowledge network. Table 6.10 states e-mail has become the most popular way to access the network; intranet scores the second place while traditional 'face to face' methods are tending to decay.

The results suggest that;

- More than half the companies do not have a formal knowledge network. This means they need to outsource provision of facade knowledge when necessary or get by without;
- ICT facilities have been widely used for information sourcing and communication in the industry, though most of them are by e-mail rather than a real-time interactive platform.

6.4.3.3 External sources (Questions 9-10)

Due to the limited internal knowledge resources, many companies relied on external resources. Questions 9-10 are to investigate the external information sources of the companies. Table 6.11 shows the overall result and Tables 6.12 – 6.18 illustrate the results of different sources separately. Table 6.19 lists the respondents' comments on other external information sources.

Question 9 How often do you use these external sources of information?

Descriptive Statistics: External sources

	Standards:	Trade associations:	Manufacturers literature:	Manufacturers advice:	Certification:	Consultants:	CWCT:
Valid	62	62	62	62	58	62	62
Missing	0	0	0	0	4	0	0
Mean	4.29	3.32	3.77	3.42	2.52	3.08	2.53

Table 6.11 Descriptive Statistics: External sources

Standards:

		Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	Often	1	1	12		9	7	30
4	sometimes	4	2	5	2	2	4	19
3	occasionally	2		1	3	1	6	13
2	seldom							
1	rarely							
	Total	7	3	18	5	12	17	62

Table 6.12 External sources: Standards

Trade associations:

		Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	Often			3			4	7
4	sometimes		1	4		7	7	19
3	occasionally	5	2	7	5	5	4	28
2	seldom	2		2				4
1	rarely			2				
	Total	7	3	18	5	12	17	62

Table 6.13 External sources: Trade associations

Manufacturers literature:

		Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	Often		1	6		4	4	15
4	sometimes	2	1	6	2	2	9	22
3	occasionally	4	1	6	3	6	4	24
2	seldom	1						1
1	rarely							
	Total	7	3	18	5	12	17	62

Table 6.14 External sources: Manufacturers literature

Manufacturers advice:

		Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	Often			5		4	3	12
4	sometimes	4	2	3			10	19
3	occasionally	3	1	4	5	2	4	19
2	seldom			5		4		9
1	rarely			1		2		3
	Total	7	3	18	5	12	17	62

Table 6.15 External sources: Manufacturers advice

Certification:

		Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	Often			12		2	3	7
4	sometimes			4		2	6	12
3	occasionally	4		3			2	9
2	seldom		1	3			6	10
1	rarely	2	2	5	2	8		19
	Total	6	3	18	2	12	17	58

Table 6.16 External sources: Certification

Consultants:

		Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	Often	2		3		2		9
4	sometimes	2		5		3	7	18
3	occasionally	2	1	3		2	2	13
2	seldom	1	1	4	2	4	4	14
1	rarely		1	3	3	1	4	8
	Total	7	3	18	5	12	17	62

Table 6.17 External sources: Consultants

CWCT:

		Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	Often			3			2	5
4	sometimes	3	1	6	2		3	15
3	occasionally	2	1	4		2	4	13
2	seldom		1	1		2	2	6
1	rarely	1		4	3	8	6	23
	Total	7	3	18	5	12	17	62

Table 6.18 External sources: CWCT

Question 10 Which other sources of information do you use?

Position	**Company type**	**Other sources of information**
Lead designer	Manufacturer (international)	Structural engineer
Senior Designer	Specialist contractor (international)	Material catalogue Software information
Technical Manager	Specialist contractor	Council for Aluminium in Building (CAB), Internet, Structural engineer
Project engineer	Specialist contractor (international)	Past project experience
Chief Consultant	Engineer/consultant (international)	Glass Association of North America (GANA), American Society for Testing and Materials (ASTM), British Standards (BS)
Senior Designer	Engineer/consultant (international)	Group knowledge, Group library
Asst Vice President	Test laboratory	Local university, Local consultants
Architectural Applications Manager	Manufacturer (international)	International Organization for Standardization (ISO), Market surveys

Table 6.19 Other external information sources

Table 6.11 implies that 'standards' are considered to be the most authoritative source and are the most widely used external source, with the mean at 4.29. 'Manufacturers literature' and 'manufacturers technical advisory service' and 'trade associations' also provide good sources for information, with the means at 3.77, 3.42, and 3.32 respectively. Table 6.12 shows that consultants, manufacturers and specialist contractors used standards most often.

As a single organisation, the CWCT won 3+ (often, sometimes and occasionally) scores from 32 of the respondents, not faraway from consultants as a whole (40). At the same time, 14 percent of the respondents have no operations in the UK, which may explain why a number of respondents rarely used CWCT as one of their external sources. Considering 'standards' include CWCT Standards and CWCT is seen as a 'trade association' (though wrongly) by some companies, it implies that CWCT has achieved a considerably high industrial significance, especially for architect, client, consultants and cladding specialist contractor (see Table 6.18).

Other external sources used by respondents are shown in Table 6.19. Although most of them have been covered in Question 9, the internet, local universities and market surveys are additional sources.

6.4.3.4 Training resources (Question 11-13)

Question 11: 1) Do you hold a qualification in facade engineering?

2) In your organisation does anybody other than you hold a qualification in facade engineering?

Descriptive Statistics: Qualification in façade engineering

	Hold a qualification:	Other holds a qualification:
Valid	58	61
Missing	4	1
Mean	1.67	1.52

Table 6.20 Descriptive Statistics: Qualification in façade engineering

Question 12: Do you have access to mid-career training (CPD)?

In you organisation does anybody other than you have access to mid-career training (CPD)?

Descriptive Statistics: Mid-career training (CPD)

	Undertake CPD:	Other undertake CPD:
Valid	53	54
Missing	9	8
Mean	1.42	1.43

Table 6.21 Descriptive Statistics: Mid-career training (CPD)

Company type	Hold a Qualification		Other holds a Qualification		Undertake CPD		Other undertake CPD	
	f	%	f	%	f	%	f	%
Architect	4	57.1	2	28.6	4	57.1	3	42.9
Client	0	0	1	33.3	1	33.3	2	66.7
Engineer/consultant	7	38.9	12	66.7	9	47.4	7	36.8
Main contractor	1	20	3	60	2	40	4	80
Manufacturer/supplier	4	33.3	2	16.7	9	75	7	58.3
Specialist contractor	3	17.6	9	52.9	7	41.2	9	52.9
Total	19	30.6	29	46.8	32	50	32	50

Table 6.22 Training resources

Table 6.22 shows 19 of the respondents have a qualification in facade engineering, and 32 have access to mid-career training. Considering that most respondents hold senior positions in the industry, there is obviously a lack of professional training. At the same time, 46.8 percent of the respondents have colleagues who hold a facade qualification and 50 percent have access to mid-career training. Generally, architects did better than others on training programme.

This shows the reality that many organisations, including specialist contractors and manufacturers, have no employees holding facade engineering qualifications and provide no mid-career training for their workforce. The practitioners in the industry should be better trained. More training sources should be provided.

Question 13: (If you answered yes to question 12) Which training providers do you use?

Position	**Company type**	**Training providers**
Product Manager	Manufacturer (international)	In house international training
Lead designer	Manufactures/ suppliers European operating in UK	CWCT training Health & safety training
Architect	Architect international	Autodesk CAD training
Senior Designer	Specialist contractor (international)	AutoCAD training Inventor training
Operations director	Specialist contractor	CWCT Training
Technical Manager	Specialist contractor	CWCT Training Construction Skills Certification Scheme (CSCS)
Structural engineer	Specialist contractor	Technical training
Head of Department	Specialist contractor	Technical Managerial
Director	Engineer/consultant	CWCT
Chief Consultant	Engineer/consultant	In-house
Lecturer	Engineer/consultant	Many different types of CPD
Senior Designer	Engineer/consultant	Own company training schemes CWCT
Operations Director	Engineer/consultant	Chartered Institute of Arbitrators Institution of occupational Safety and Health (IOSH)
Asst Vice President	Test Laboratory	Local service provider German HQ
Architectural Applications Manager	Manufacturer (international)	Homologated Testing Laboratories Conference & Seminars Fairs

Table 6.23 Training providers

Table 6.23 shows 15 respondents listed their training providers. CWCT was mentioned by five practitioners from two consultants, two specialist contractors and one manufacturer respectively. This implies CWCT's training programme has been recognised by the industry. Other training sources include software providers, various service providers, and certification schemes provider.

6.4.3.5 QA procedure (Question 14)

Question 14: What, if any, QA procedures are applied to sources of information?

- I have open access to information on the internet
- There is a corporate filter through an intranet or other interface

Descriptive Statistics: QA procedures

Valid	57
Missing	5
Mean	1.39

Table 6.24 Descriptive Statistics: QA procedures

QA procedures are applied to sources of information

Company type	**Open access**	Percent	**Filter**	Percent
Architect	4	57.1	3	42.9
Client	2	66.6	1	33.3
Engineer/consultant	14	77.8	3	16.7
Main contractor	3	60	2	40
Manufacturer/supplier	6	50	5	41.7
Specialist contractor	8	47.1	8	47.1
Total	36	56.3	23	35.9

Table 6.25 QA procedures are applied to sources of information

The results show that 36 of the respondents (56.3%) have open access to information on the internet compared with 23 (35.9%) who have a corporate filter. There is no one group that has more than half of its respondents using this QA facility. Especially, only 16.7 percent of the engineers/consultants have a filter through an intranet or other interface. It hints that QA procedures to sources of information have not been properly established in the industry, though the ICT facilities and solutions have been extensively used.

6.4.3.6 Comments for extra-project level information sources (Question 15-17)

Questions 15-17 are to collect suggestions for the development of extra-project level information sources. It was predicted that these questions might be regarded as 'others' responsibility' by the respondents; however surprisingly, they were carefully completed by many respondents. It clearly shows that this industry has the passion for interaction and improvement.

Question 15 Outside of the facade engineering field what do you believe are good examples of providing technical information?

Position	Company type	Good examples
Product Manager	Manufacturer (international)	Technical Consultancy/Specifications Technical forums Website
Lead Designer	Manufactures/ suppliers European operating in UK	Literatures Websites
Architect	Architect (international)	Royal Institute of British Architects (RIBA)
Architect	Architect (international)	Product Literature& specifications
Senior Designer	Specialist contractor (international)	Aero dynamics Sustainable design
Operations Director	Specialist contractor	British Standards Structural engineering
Technical Manager	Specialist contractor	CD, Brochures Interactive IT on internet, E-mail

Project Coordinator	Specialist contractor (international)	Internet
Project Engineer	Specialist contractor (international)	ICE Structural engineering Journals
Structural Engineer	Specialist contractor	Journals-structural engineering
Head of Department	Specialist contractor	Universities Journals
Technical Manager	Specialist contractor	Chartered Institution of Building Services Engineers (CIBSE); Chartered Institute of Building (CIOB); Energy saving trust
Director	Engineer/consultant	Glass Performance Days
Chief Consultant	Engineer/consultant	Sweets Catalogues Architect's First Choice
Lecturer	Engineer/consultant	Standards On-line information
Principal Facade Designer	Engineer/consultant (international)	Seminar
Facade Engineer	Engineer/consultant	Conference, seminars, lectures and research; Interaction with other trades
Technical Director	Engineer/consultant	Internet Industry design guides (BRE etc)
Design Leader	Engineer/consultant (international)	Automotive
Senior Engineer	Main contractor (international)	Journals
Asst. Vice President	Test Laboratory	Company intranet Company forum
Architectural Applications Manager	Manufacturer (international)	Universities (thesis) Scientific newspaper/journal Testing laboratories

Table 6.26 Good examples of providing technical information

Question 16 What guidance would you like to access that you are not currently aware of?

Position	**Company type**	**Guidance**
Senior Designer	Specialist contractor (international)	Renewable energies
Operations Director	Specialist contractor	Quality 'ISO'
Technical Manager	Specialist contractor	A guide to general installations (Specifically to facades)
Project Coordinator	Specialist contractor (international)	Standards
Head of Department	Specialist contractor	Façade movement
Architectural Applications Manager	Manufacturer (international)	Glass and Glazing

Table 6.27 Guidance

Question 17 What Standards do you think should be developed?

Position	**Company type**	**Standards**
Head of Department	Specialist contractor	Specifications for compatibility
Director	Engineer/consultant	Safe use of glazing configurations
Operations Director	Engineer/consultant	Allowable centre pane glass deflection
Technical Director	Engineer/consultant	Glass design!
Architectural Applications Manager	Manufacturer (international)	Mechanical strength

Table 6.28 Standards

Table 6.26 shows the suggested good examples of providing technical information beyond the field of facade engineering. On-line resources, journals, forums, seminars and researches are intensively referred to. 'Automotive' is noted by a design leader in a manufacturer, which implies some manufacturers have been learning from more advanced industries.

The results of ‘guidance you would like to access that you are not currently aware of’ include renewable energies, Quality ‘ISO’, facade installation, standards, facade movement, and glass and glazing (Table 6.27).

For the results of ‘Standards you think should be developed’ shown in Table 6.28, it is noticeable that three out of five respondents emphasized glazing and glass, even with an exclamation mark.

The comprehensive results of these three questions indicate the wide gap of information sources and respondents’ enthusiasm to narrow it. It also suggests that a successful knowledge repository should be an interactive and dynamic system.

6.4.4 Intra-project level (Questions 18-21)

6.4.4.1 Project information in IT platforms (Questions 18-19)

Questions 18 and 19 are to investigate what specific project information IT platforms contain. Table 6.30 shows the overall descriptive statistical results for the six types of project information hosted by IT platforms. Table 6.31 shows the differing results between six professional groups. The detailed results for the six types of intra-project level information are included in Appendix E. Table 6.32 shows the respondents’ opinions of what additional information should be also held.

Question 18 If you have used an extranet or other IT platform to host project information what did it contain?

Descriptive Statistics: project information in IT platforms

	Drawings	Specifications	Method statement	Standards	Supporting information	Health and safety
Valid	60	60	60	60	60	57
Missing	2	2	2	2	2	5
Mean	1.28	1.33	1.43	1.43	1.45	1.47

Table 6.29 Descriptive Statistics: project information in IT platforms

Company type	Drawings:		Specifications:		Method statement:		Standards		Supporting information:		Health and safety:	
	f	%	f	%	f	%	f	%	f	%	f	%
Architect	7	100	5	71.4	2	28.6	7	100	7	100	2	28.6
Client	2	66.6	1	33.3	1	33.3	3	100	1	33.3	2	66.6
Engineer/consultant	11	61.1	11	61.1	9	50	10	55.6	9	50	7	38.9
Main contractor	5	100	5	100	3	60	5	100	3	60	3	60
Manufacturer/supplier	7	58.3	7	58.3	10	83.3	7	58.3	9	52.9	10	83.3
Specialist contractor	11	64.7	11	64.7	11	64.7	5	29.4	11	91.7	6	35.3
Total	43	67.2	40	62.5	34	53.1	34	53.1	33	51.6	30	46.9

Table 6.30 Project information in IT platforms

Question 19 If you have used an extranet or other IT platform to host project information what additional information should it have held?

Position	**Company type**	**Additional information**
Project engineer	Specialist contractor (international)	Time sheet Expense claim form
Head of Structure Department	Specialist contractor	Specification for testing
Architectural Applications Manager	Manufacturer (international)	Specific regulations on the use of safety glass in building in Europe

Table 6.31 Additional project information in IT platforms

Table 6.29 shows 60 of the 62 respondents replied to question 18, which means most of them have experience using an extranet or other IT platform to host project information. Among the six types of information, drawings and specification are the most basic information to be provided in the platform, with the mean at 1.28 and 1.33. Health and safety information has the lowest score. On the other hand, Table 6.30 shows that the usage of IT platforms varies with different groups. For instance, all of the architects, clients and main contractors use IT platforms to contain standards, compared with only 29.4 percent of the specialist contractors. Table 6.31 shows a wish for 'time sheet and expense claim form' to be included in the IT platform, but it may be only applicable for open book contracting. 'Specification for testing' and 'specific regulations on the use of safety glass in building in Europe' were also requested although they are actually categorized as extra-project level information. However, it shows the close relationships between extra-project information and intra-project usage. At the same time, glass is mentioned again which indicates the dramatic information gap on glass.

6.4.4.2 Barriers to accessing information (Question 20-21)

According to the initial interviews, there are a number of barriers for practitioners in the industry that prevent access to information. Questions 20-21 are to investigate the barriers when practitioners work on a specific project. Table 6.32 shows the overall result and Tables 6.33-6.37 illustrate the results of different barriers separately. Table 6.38 lists the respondents' comments on other barriers to information sources.

Question 20 To what extent are the following barriers to accessing information when working on a project?

Descriptive Statistics: Barriers to accessing information

	Time scale:	Work load:	Inability to access:	Inability to agree:	Conflicting information:
Valid	62	62	62	62	61
Missing	0	0	0	0	1
Mean	3.95	4.00	3.03	2.56	3.06

Table 6.32 Descriptive Statistics: Barriers to accessing information

Time scale:

	Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5 Often	2	1	3	2	5	8	21
4 Sometimes	5	1	7		5	7	25
3 occasionally		1	3	3	2	2	11
2 seldom			2				2
1 rarely			3				3
Total	7	3	18	5	12	17	62

Table 6.33 Barriers to accessing information: Time scale

Work load:

	Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5 Often	3	1	3		7	8	22
4 sometimes	4	2	9		2	5	22
3 occasionally			3	5	3	4	15
2 seldom			2				2
1 rarely			1				1
Total	7	3	18	5	12	17	62

Table 6.34 Barriers to accessing information: Work load

Inability to access sources:

	Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5 Often	1	1	2		6		10
4 sometimes	4	1	3	2	4	2	16
3 occasionally	2	1	4	3	2	10	22
2 seldom			3			5	8
1 rarely			2				2
Total	7	3	18	5	12	17	62

Table 6.35 Barriers to accessing information: Inability to access sources

Inability to agree sources:

	Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5 Often			3				3
4 sometimes	3	1	4			6	14
3 occasionally	2	1	7	3	4	2	19
2 seldom	2	1	4	2	4	4	17
1 rarely			3		4	5	12
Total	7	3	18	5	12	17	62

Table 6.36 Barriers to accessing information: Inability to agree sources

Conflicting information:

	Architect	Construction client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5 Often				2		2	4
4 sometimes	4	1	4	3	2	8	18
3 occasionally	1		5		10	3	22
2 seldom	2	2	5			2	11
1 rarely			4			2	6
Total	7	3	18	5	12	17	61

Table 6.37 Barriers to accessing information: Conflicting information

Question 21: What other barriers to accessing information have experienced?

Position	**Company type**	**Other barriers to accessing information**
Lead designer	Manufactures/ suppliers	Lack of co-ordinated procedures of all sub-contractors
Architect	Architect international	very little significant literature is available
Senior Designer	Specialist contractor (international)	Shared software licenses
Operations Director	Specialist contractor	Shared software licenses
Technical Manager	Specialist contractor	Unhelpful suppliers
Project Coordinator	Specialist contractor (international)	Regular meetings
Head of Department	Specialist contractor	Mainly lack of time
Principal Facade Designer	Engineer/consultant (international)	Time zone when working internationally
Facade Engineer	Engineer/consultant	Vague/Lack of information
Senior Engineer	Main contractor (international)	Contradictory specification requirements Commercial approach
Technical Director	Engineer/consultant	Long time to download data
Architectural Applications Manager	Manufacturer (international)	Language

Table 6.38 Comments on other barriers to accessing information

Table 6.32 shows 'work load' and 'time scale' to be the top two barriers to accessing information, with the mean at 4.00 and 3.95. This suggests current information sourcing is fairly time consuming and difficult. Especially for manufacturers and specialist contractor (see Table 3.33 and 3.34), there is a need to rebalance project timetables. On 'inability to access sources', 'inability to agree sources', and 'conflicting information' respectively, 38, 35 and 44 of the 62 respondents marked 3+ (often, sometimes and occasionally). This means the practitioners in this industry are highly affected by these three barriers. In particular, six of the twelve manufacturers are often unable to access intra-project information (see Table 6.36), which indicates 50 percent of manufacturers can not be fully involved in the project-specific cladding design and procurement.

Other barriers pointed out by respondents have been listed in Table 6.38. “Lack of co-ordinated procedures of all sub-contractors” from a manufacturer (Lead designer) and “unhelpful suppliers” from a specialist contractor (Technical manager) clearly exposes the adversarial attitudes between participants in the cladding supply chain.

6.4.5 CWCT focus (Questions 22-25)

This section (Questions 22-25) is to examine the view of the industry on the CWCT website and Technical Notes. The CWCT website can be seen as an extra-project level information hub, with well-organized technical, training and general information. Also, a member forum is included. The CWCT Technical Notes are a series of summaries on cladding technical and managerial knowledge. Most of them are produced to respond the demands of the CWCT membership and industry developments, and they are updated regularly; thus, it can be seen as an interactive knowledge bank.

This section actually was intended to act as a validation of an Information and communication hub run by an industry level third party, especially at the extra-project level.

6.4.5.1 The CWCT website (Question 22-23)

Question 22 is to measure the performance of the CWCT website from five perspectives: technical authority, technical quality, independence, ease of use and functionality. Question 23 invites the respondents to give their suggestions for other information which they would like to find on the website in the future. Table 6.39 shows the overall results and Tables 6.40-6.41 illustrate the results of five different aspects separately. Table 6.46 lists the respondents’ comments on other information they would like to find.

Question 22: How do you rate the CWCT website?

Descriptive Statistics: the CWCT website

	Technical authority:	Technical quality:	Independence:	Easy to navigate:	Useful:
Valid	60	60	60	60	60
Missing	2	2	2	2	2
Mean	4.02	4.02	3.92	3.71	3.90

Table 6.39 Descriptive Statistics: the CWCT website

Technical authority:

	Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5 very good	1	1	7		4	6	24
4 good	2	2	5	2	4	9	20
3 average	2		5	3	4	2	12
2 below average	2						2
1 poor							2
Total	7	3	17	5	12	17	60

Table 6.40 The CWCT website: Technical authority

Technical quality:

	Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5 very good	1	2	9	2	6	6	25
4 good	2	1	3	3	3	3	14
3 average	2		5		3	8	19
2 below average	2						2
1 poor							
Total	7	3	17	5	12	17	60

Table 6.41 The CWCT website: Technical quality

Independence:

		Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good	2	5	9		2	6	21
4	good	1		3	2	2	4	12
3	average	4		5	3	8	7	27
2	below average							
1	poor							
	Total	7	3	17	5	12	17	60

Table 6.42 The CWCT website: Independence

Easy to navigate:

		Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good			10		2	6	18
4	good	5	3	4		6	9	27
3	average			2	5	4	2	13
2	below average	2		1				3
1	poor							
	Total	7	3	17	5	12	17	60

Table 6.43 The CWCT website: Easy to navigate

Useful:

		Architect	Client	Engineer/ Consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good	3	1	10		4	8	25
4	good		2	4		2	4	12
3	average	2		2	3	6	3	16
2	below average			1	2		2	5
1	poor	2						2
	Total	7	3	17	5	12	17	60

Table 6.44 The CWCT website: Useful

Question 23: What other information would you like to find on the CWCT website?

Position	**Company type**	**Other Information**
Architect	Architect (international)	Façade basics for beginners; Structural studies relevant to façade
Senior Designer	Specialist contractor (international)	Approved software
Technical Manager	Specialist contractor	Up and coming technologies; General test results
Principal Facade Designer	Engineer/consultant (international)	Documentation of failures
Facade Engineer	Engineer/consultant	Technical design guides
Senior Engineer	Main contractor (international)	Case studies

Table 6.45 Comments on further development of the CWCT website

The results state that the majority found the CWCT website 'Very good / Good' from all five perspectives. Table 6.39 indicates 'Technical authority' and 'Technical quality' of the CWCT website scores very high, with the mean at 4.02. The other three aspects also performed well, especially the 'Independence' for which all respondents replied above average. It is also noticeable that almost all manufacturers and specialist contractors rated the five aspects with 3+ (Very good, good and average) (across Table 6.40 to Table 6.44).

Table 6.45 shows the respondents' interests of information, most of them are very practical, for instance, documentation of failures and case studies.

6.4.5.2 The CWCT Technical Notes (Question 24-25)

Question 24 would evaluate the CWCT Technical Notes (TNs) on five aspects: technical authority, technical quality, independence, relevance and easiness of understanding. Question 25 inquiries the respondents' opinions on further development of TNs. Table 6.46 states the overall results and Tables 6.47-6.51 illustrate the results of five different aspects separately.

Table 6.52 discovers the respondents' wishes of further development of the technical notes.

Question 24: If you have used the CWCT Technical Notes how do you rate them?

Descriptive Statistics: the CWCT Technical Notes

	Technical authority:	Technical quality:	Independence:	Relevance:	Easy to understand:
Valid	59	59	59	59	59
Missing	3	3	3	3	3
Mean	4.36	4.41	4.22	4.07	4.36

Table 6.46 Descriptive Statistics: the CWCT Technical Notes

Technical authority:

		Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good	4	2	13	2	2	5	28
4	good	1	1	2	3	9	11	24
3	average	2		2				7
2	below average							
1	poor							
	Total	7	3	17	5	11	16	59

Table 6.47 The CWCT Technical Notes: Technical authority

Technical quality:

		Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good	6	2	8	2	11	5	34
4	good	1	1	7	3		7	15
3	average			2			4	10
2	below average							
1	poor							
	Total	7	3	17	5	11	16	59

Table 6.48 The CWCT Technical Notes: Technical quality

Independence:

		Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good	3	2	12	3	4	5	28
4	good	3		2	2	5	6	16
3	average	1	1	3		2	5	15
2	below average							
1	poor							
	Total	7	3	17	5	11	16	59

Table 6.49 The CWCT Technical Notes: Independence

Relevance:

		Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good	2	1	6		5	5	19
4	good	3	1	10		6	7	27
3	average	2	1	1	5		2	11
2	below average						2	2
1	poor							
	Total	7	3	17	5	11	16	59

Table 6.50 The CWCT Technical Notes: Relevance

Easy to understand:

		Architect	Client	Engineer/ consultant	Main contractor	Manufacturer/ supplier	Specialist contractor	overall
5	very good	5	2	11		9	5	32
4	good		1	4		2	9	16
3	average	2		2	5		2	11
2	below average							
1	poor							
	Total	7	3	17	5	11	16	59

Table 6.51 The CWCT Technical Notes: Easy to understand

Question 25: What other CWCT technical notes would you like us to produce?

Position	**Company type**	**Other Technical Notes**
Architect	Architect (international)	Intelligent skins & façade; Structural studies relevant to façade
Senior Designer	Specialist contractor (international)	Technical details of drawings; Approved software assistance
Operations Director	Specialist contractor	Method statements
Technical Manager	Specialist contractor	Test results for (structural glass, brackets, door - manual/automatic); Fire rated curtain wall in aluminium; Other alloys
Project Coordinator	Specialist contractor (international)	Façade life cycle-maintenance & management cost; Standards for adhesives - life cycle
Structural Engineer	Specialist contractor	Standards
Head of Department	Specialist contractor	Movement; Cable supported structures; Wide span façade
Technical Manager	Specialist contractor	Thermal bridges standard design procedures; Role of façade in environmental performance
Facade engineer	Engineer/consultant	Method statement
Principal Facade Designer	Engineer/consultant (international)	Load share of DGU- test results; Pressures in a spandrel zone- between glass and shadow box.
Facade Engineer	Engineer/consultant	Glass design; Stone, precast and masonry; Tensile structures and cable nets
Senior Engineer	Main contractor (international)	Cutting edge technologies; Global warming; New energy sources

Table 6.52 Comments on further development of the CWCT Technical Notes

The results state that the majority found the CWCT Technical Notes ‘Very good / Good’ from all five perspectives, with the mean above 4. Almost all the respondents rated them above average on the five aspects except two specialist contractors give a below average on ‘Relevance’ (Table 6.50). It implies the CWCT Technical Notes have gained deep recognition and wide support from the industry.

Table 6.52 lists the wide spectrum of respondents' demands for technical documentation. Many of them are fairly new to the industry, such as "Cutting edge technologies, global warming and new energy sources", while others are traditional issues, like "Tensile structures and cable net". As a dynamic system, it is very important to keep the knowledge database updated according to requirements from the industry.

6.4.6 Findings

This questionnaire survey was designed to explore the information sources available and used by industry practitioners, verify the findings from the interviews, test the conceptual model proposed in Chapter 5, and provide fresh ideas for the development of the framework. The significant features of the new communication model include: an Information and communication Hub with a two-level information exchange structure and the involvement of a third party. Therefore, the main questions of the questionnaire were categorised into three sections: extra-project level, intra-project level and a third party testing, and sections 6.4.3 – 6.4.5 presented the results of the survey accordingly.

The following are the findings from the results of the questionnaire survey:

Finding 1. Currently, different parties rely on various types of information sources, and the formality of and QA procedures applied to information sources are inadequate.

Results of Q5 and Q9 present the diversity of the information sources and demands between different parties. Results of Q6-Q7 illustrate the inadequate formality of knowledge networks and results of Q14 shows the lack of QA procedures applied to sources of information.

In this research, in-house information sources mainly include library, intranet, specialist, project or section manager, line manager and knowledge network (Q5); while external knowledge sources comprise standards, trade association literature, manufacturer literature, manufacturer technical advisory service, certification schemes, consultants, and the CWCT (Q9).

The types of information sources that different groups use are characterised by the nature of their work. In general, the clients have the most limited information sources on cladding. None of them have a facade knowledge network and they use the external cladding information sources relatively infrequently. This reflects the reality that clients do not need to focus on the cladding aspect. Main contractors have no company libraries due to the temporary nature of the construction sites, while all consultants have company libraries as they are working in a relatively stable office. A consultant often needs to play the role of a coordinator between parties, which means the consultant has the most balanced information sources. Most respondents from the parties other than the client have in-house specialists; this indicates the increasing complexity and importance of facade engineering.

Regarding external sources, the majority of the consultants, manufacturers, and specialist contractors use standards and other external sources more frequently than the other three parties; this matches their roles of cladding-focused service providers in the supply chain and their need for more specific information than clients, architects and main contractors. They still need to outsource the information and knowledge that they do not have internally. This means, in fact, that these three parties need more external information providers and the results of the CWCT focused questions (Q22-25) further highlighted this point.

Every party has its own information sourcing style; however, the quality assurance aspects are generally flawed. Only 48% of the respondents (excluding the cladding specialists) have a formal knowledge network (16% of manufacturers, 0% of clients) (Q6-7); and only 35.9% of the respondents have QA procedures on sources of information (Q9). As a perceived informative/knowledgeable party in the cladding supply chain, only 16.7% of the consultants have QA procedures though 72% of them have a formal knowledge network. These facts imply that the information sources are often not well organised and assured, which may adversely affect decision-making.

There are diverse information sources for participants in the cladding supply chain, but the quality of the information sources is not secured. It is difficult for participants to indentify the appropriate information sources, and this may explain the results of Q20, showing that the participants frequently disagree with external sources of information and encounter conflicting information.

Finding 2. The majority of the participants in the industry frequently experience difficulties of accessing information.

The results of Q20 confirm that most of the practitioners in the industry quite frequently experience barriers to accessing information, and imply that the current decision-making timeframe needs to be adjusted. The responses to Q21 indicate some key reasons for the barriers and show problems arising from fragmentation of the supply chain.

According to the results of Q20, the barriers to accessing information sources can be ranked in descending order of frequency as follows: work load, time scale, conflicting information, inability to access, and inability to agree.

All of them are marked from ‘occasionally’ to ‘often’ by the majority of the respondents. ‘Conflicting information’ and ‘inability to agree’ may be caused by diverse and unreliable information sources, as discussed under Finding 1. A facade engineer responding to Q21 pointed out that information from some sources was vague or scarce, and a main contractor cited “contradictory specification requirements”.

‘Inability to access information’ means that the practitioners are unable to share information that they need. The reasons for this have been partially exposed in responses to Q21, such as intelligence protection (“software licenses”), communication issues (“the lack of co-ordinated procedures of all sub-contractors"), as well as adversarial attitudes ("unhelpful suppliers"). Of course, some confidential information may be restricted for specific participants.

'Work load' and 'time scale' are rated as the top two barriers to accessing information. In particular, cladding specialists and manufacturers may play a key part in detailed design and system design, and they need to have the most detailed and specific information available. However, a large proportion of the manufacturers and cladding specialists suffer from accessing information sources with the reasons given as work load and time scale, which reflects that the detailed design actually needs more time to be allocated. This problem would be eased by earlier appointment of specialist contractors.

Finding 3. There are too few qualified practitioners and training opportunities for practitioners in the cladding industry are limited.

Results of Q11-12 show that there is a shortage of adequately qualified practitioners (decision makers) and education/training opportunities for practitioners in the industry are limited.

The professional education and training levels partially determine the quality of the decision makers and of the decisions they make. Facade engineering was traditionally an 'empirical' form of engineering with people learning from one another 'on the job'; however, the increasing complexity of building facades requires the decision makers to have more structured theoretical knowledge. At the same time, the education and training providers are an important information sources for the participants. The results of Q11-12 show that only 30.6 percent of respondents hold qualification in facade engineering and 50 percent of them have no access to mid-career training. It suggests many practitioners of the industry need to be further trained and relevant companies should provide more opportunities for education and training of their employees.

Finding 4. ICT facilities have been widely used in the construction industry, but there is still a large potential for improvement.

The results of Q8 show the majority of the respondents use ICT facilities instead of the traditional 'face to face' method of accessing the facade knowledge network. The results of Q18 show almost all the respondents have experience of using an extranet or other IT platforms to host project information. These results actually show that ICT facilities have been widely used in the construction industry. However, it is also implied that the usage of electronic applications has a big potential for improvement in the industry. For instance, all the respondents from main contractors use e-mail to access a facade knowledge network but no one uses an extranet, and most IT platforms only contain basic information, such as drawings and specification, rather than performing as interactive communication and collaborative decision-making platforms. Therefore, the industry still has a long way to go to make the best use of ICT and modern electronic applications.

Finding 5. An industry level third party could be well accepted by the cladding industry, especially as an independent information source, knowledge base and training provider.

It was not practical to ask the respondents to imagine a third party and ask for comments on whether they would recognise its performance and accept it to be involved in their information sourcing strategy or communication framework. Any response would be wholly dependent on what the respondent imagined. Therefore, the author used a practising non-trade organisation, the Centre for Window and Cladding Technology (CWCT), as the third party in the questionnaire survey to test the acceptance/performance of such a body.

In the conceptual model proposed in Chapter 5, the third party mainly plays the role of the developer and manager of the Information and Communication Hub, which consists of an IT platform and an interactive knowledge base. The CWCT website (http://www.cwct.co.uk) can be seen as a web-based portal filling the role of an extra-project level information hub, providing well-organized technical, training and general information. Also, a member forum is included. The CWCT Technical Notes are a series of summaries on cladding technical and managerial knowledge. Most of them are produced in response to the demands of the CWCT members and industry development, and they are updated regularly according to the recent changes in Regulations and Standards and industry revisions; thus, it can be seen as an interactive knowledge base.

Questions 22 and 24 examined the industry's view on the CWCT website and Technical Notes (TNs) respectively from the following five perspectives: technical authority, technical quality, independence, relevance/usefulness, and ease of use. The percentages of responses rating the CWCT website/ Technical Notes above 'Good' are summarised in Table 6.53.

	CWCT website (Very good/Good)	CWCT Technical Notes (Very good/Good)
Technical authority	72.9	88.2
Technical quality	74.4	78.2
Independence	55.9	74.6
Relevance/usefulness	62.7	78
Ease of use	54.2	81.3

Table 6.53 The percentages of responses rating the CWCT website/TNs 'Very good/ Good'

The results state that the majority of the respondents from the industry recognise the web-based portal and knowledge base of the CWCT are good or very good, and suggest that a web-based portal and dynamic knowledge base of an industry level third party can be widely supported by the industry.

In addition, the results of Question 9 show that the CWCT, as a single organisation, has been seen as an important external information source by many respondents, especially consultants and specialist contractors. Five of the fifteen responses to Question 13 ("Which training providers do you use?") mentioned the CWCT as their training provider, which confirms a third party can play an important role on training and education for the industry. Clearly, an independent training provider may give decision makers more balanced knowledge and information than an interested party, such as a system manufacturer.

All the positive feedback on the performance of the CWCT indicates an industry level third party can be well accepted by the industry, especially as an independent information source, knowledge base and training provider.

Therefore, there are five main findings from the analysing the results of the questionnaire:

- Finding 1. Currently, different parties rely on various types of information sources, and the formality of, and QA procedures applied to, information sources are inadequate.
- Finding 2. The majority of the participants in the industry frequently experience difficulties of accessing information.
- Finding 3. There are too few qualified practitioners and training opportunities for practitioners are limited in the cladding industry
- Finding 4. ICT facilities have been widely used in the construction industry, but there is still a large potential for improvement.
- Finding 5. An industry level third party could be well accepted by the cladding industry, especially as an independent information source, knowledge base and training provider.

6.5 Examination of the conceptual model

The interviews and the questionnaire survey were carried out based on and for the development of the conceptual model of Integrated Communication and Decision-making (ICDM) proposed in Chapter 5. The findings of the interviews and the questionnaire survey have been summarised respectively at the end of their own sections. This section examines the conceptual model.

Revisiting the conceptual model, it is found the responses from the interviews and the questionnaire survey are positive and support this idea and in fact, the questionnaire survey has partially tested the model from the perspectives of its necessity and feasibility; that is,

1. There is a need for an information and communication hub in the cladding supply chain;
2. An industry level third party can be widely accepted by the cladding industry.

In addition, the findings of the survey also provide suggestions for modifications and further development of the conceptual model.

1. There is a need for an information and communication hub in the cladding supply chain

The increasing complexity of cladding materials and solutions has greatly widened the knowledge gap between the different parties. The knowledge and specialist expertise has been dispersed into different parties within the cladding supply chain and most of the participants suffer from the lack of sufficient information sources to different degrees. This requires the industry to work in a more collaborative way and make decisions by the right persons at the right levels. The interviewees commonly recognised that sufficient information and effective communication were the key factors for better decision making.

However, from the Finding 1 and Finding 2 (which are supported by the results of Q5-9, Q14, and Q20-21) the participants within the cladding supply chain are experiencing difficulties of identifying information sources and accessing information. Also, the adversarial attitudes between parties were shown in both the interviews and the questionnaire survey (the results of the Q21). These issues have significantly affected the information flow and decision-making.

An appropriate I&C Hub, as proposed in section 5.4, can provide an accessible integrated information source, dynamic knowledge base and a communication platform. If the hub is run by a non-trade third party, the adversarial attitudes will be reduced as there are no direct conflicting interests between the third party and original participants of the supply chain.

Additionally, Finding 3 (There are too few qualified practitioners and training opportunities for practitioners in the cladding industry are limited.) and Finding 4 (ICT facilities have been widely used in the construction industry, but there is still a large potential for improvement.) show the problems of the training and ICT usage respectively in the cladding industry. The findings indicate that the decision makers in the industry need to be further trained and ICT tools should be developed and more widely used. It suggests there is a need for an industry level training provider and ICT promoter. Therefore, the I&C Hub has the potential to play an important roles as an ICT promoter for the industry and an external training provider for decision makers.

There is a need for the cladding industry to have an I&C Hub acting as an integrated information source, communication platform and industry level integrator.

2. An industry level third party can be widely accepted by the cladding industry

The ten sub-questions of the Q22 and Q24 take the role of a validation survey on the web-based portal (IT platform) and interactive knowledge base developed and managed by a third party. The results show that a majority of the respondents found the CWCT website and Technical Notes “Very good/ Good” (Table 6.53) from the all five aspects of technical authority, technical quality, independence, relevance/usefulness, and ease of use.

The results, combined with the results of Q9 and Q13, have been summarised as Finding 5, ‘an industry level third party can be well accepted by the cladding industry, especially as an independent information source, knowledge base and training provider’. In fact, according to the findings of interviews, some small and medium size cladding specialists have treated the CWCT as their R&D Department due to the lack of internal resources.

However, it needs to be indicated that all of these functions are related to the extra-project level information rather than intra-project level communication. The proving of the function and performance of a third party in the intra-project level needs to be conducted in real projects in the future.

Validation

Complete validation of the ICDM needs to be carried out in real case studies. However, in this exploratory research, limited by the immaturity of the on-line software and the author’s resources, the necessity and feasibility of the conceptual model were chosen to be tested in the first instance, while the further validation in pilot projects has to be conducted in the future. The questionnaire survey and interviews gave preliminarily confirmation that two important elements of the concept were viable and appropriate.

Technically, the current ICDM is not a validated model, but rather a conceptual model that has passed the preliminary validation tests. The further validation in real case studies should be put as a top priority for future research.

6.6 Challenges of implementation

According to the results of the questionnaire survey and interviews, there are the following challenges to establish the I&C Hub and implement the ICDM;

- The qualifications of the practitioners
- The adequacy of the ICT facilities
- Overcoming some customs of the industry
- Establishing a business model of the I&C Hub
- Competence of the third party

The qualification of the practitioners

The practitioners are the potential decision makers during the processes of the cladding design and procurement. Their qualifications and understanding not only affect the quality of the decisions they make, but also exert considerable influence on the collaboration within the supply chain and the impact of the I&C Hub /ICDM.

However, from the Finding 3, the qualification and training opportunities of the practitioners in the industry are at an insufficient level, which means the ICDM is at the risk of being misunderstood and misused. Therefore, the third party which runs the I&C Hub must have the ability to train and guide the participants.

The adequateness of the ICT facilities

From the questionnaire and interviews, ICT facilities have been widely employed by the industry. However, there is a lack of mature software for the I&C Hub specific to the cladding sector, especially for the use of real-time inter-organisational communication at intra-project level. The web-based software demonstrated in Chapter 5 is only at its early stage. For practical implementation, a professional IT service provider would have to be involved to cooperate with the 'hub manager' to deliver secure and independent software for this platform.

Customs of the industry

Some customs of the industry were found need to be in need of change during this research. For instance, according to the results of the Q20, half of the manufacturers/suppliers are 'often' unable to access project-specific information sources. Traditionally, the contractors just 'buy' building materials and components from the manufacturers without providing them with detailed project information; however, this should change under the current circumstances of increasing complexity of the building facades and the widening knowledge gap. Early involvement and fuller involvement of specialist contractors is necessary for better design and procurement, and the implementation of the ICDM.

Business model of the I&C Hub

"Who pays?" is often the first question that interviewees asked as soon as the author started to describe the conceptual model and I&C Hub. A business model of the I&C Hub needs to be developed that gives it economic independence.

Competence of the third party

Independence, sufficient technical and financial resources and wide industry support are all critical for the success and acceptance of the third party. However, the fully competent third party which is able to develop and manage the I&C Hub is difficult to indentify in the cladding sector and needs to be tested in practice.

6.7 Summary

This chapter presented data collection and analysis. The data collection mainly used a questionnaire circulated in the cladding industry, while industry meetings and interviews were employed prior to the questionnaire survey to discover the realities of the industry and develop the ICDM proposed in Chapter 5. The understanding gained from the industry meetings and interviews informed the questionnaire design.

The questionnaire survey was designed to explore the information sources available and used by industry practitioners, verify the findings from the interviews, test the conceptual model, and provide fresh ideas for the development of the framework. 62 valid feedbacks were received and analysed. The results were summarised as five findings and proved that:

- There is a need for an information and communication hub in the cladding supply chain.
- An industry level third party can be widely accepted by the cladding industry.

The findings from the results of the survey also implied some challenges in establishing an I&C Hub and implementing the ICDM.

Chapter 7 Rethinking of the ICDM

7.1 Introduction

Chapter 6 analysed the data collected by an industry survey, and the findings proved the necessity for, and partial feasibility of, ICDM. This chapter proposes a number of modifications on the I&C hub and information flows within the ICDM to enhance its practicality.

7.2 Modifications of the I&C Hub

Analysis of the questionnaire presented in Chapter 6 suggests a number of refinements to the I&C Hub. These are:

1. The facility to add company specific technical advice
2. The facility for companies to filter sources of technical information
3. The integration of information in databases with that held on drawings
4. Response to the need for rapid and timely access to information
5. An integration of functions

7.2.1 The facility to add company specific technical data

The response to the questionnaires shows that 60% of clients, architects, consultants and main contractors have ‘façade knowledge teams’ within their organisations. Companies invest in these to reduce the financial and technical risks associated with the design and construction of building envelopes and also to give them a commercial advantage when competing for work. ‘Façade knowledge teams’ may think the I&C Hub a threat to their existence and companies may wish to distinguish themselves from others by having advanced skills and working to higher standards. It would be a useful feature of the I&C Hub if, in addition to external technical resources such as Standards and agreed specifications, companies could embed their own internal technical advice and expertise in the I&C Hub as used by them.

Companies may not wish to release this information widely but it could appear as technical advice and support only to those within the company and not the wider project team. Companies may be prepared to share technical guidance with other parties in a contract and that would mirror current practice with the exchange of paper or electronic documents.

It may happen that such advice becomes embedded in widely accepted standards and advice, again mirroring current practice.

7.2.2 The ability for companies to filter technical resources

The response to the questionnaire shows that 36% of companies control access to external technical resources through some form of filter. This is likely to be a simple restriction on URLs that can be accessed. Information providers are therefore accepted or rejected in total on the basis of their credibility and independence as information providers. This has a number of implications for the operation of the I&C Hub.

Companies may accept the I&C Hub as a filter and simply accept all technical resources available within it. However, it is unlikely that the range of technical resources will completely match what a company may wish to use, or exclude. The facility for a company to apply a filter to the links to technical resources within the I&C Hub may make its use more acceptable to them.

This facility to select which technical resources are available to a particular project has further advantages. For any project it will be necessary to decide which Standards are to apply; CEN, ASTM, ISO, CWCT. Some projects will have Standards imposed on them such as those published by the National House Building Council (NHBC) for new dwellings in the UK or by National Building Regulations and Building Codes.

7.2.3 The integration of information in databases and on drawings

The response to the questionnaire shows that currently the greatest use of extranets is for the exchange of drawings. Drawings are the best way to store and exchange spatially varying data and spatially dependent data such as tolerances. This has implications for the development of the I&C Hub.

Most immediately the I&C Hub would be more useful if it was linked to drawings or sketches. This could be by including a drawing store within the I&C Hub but there are many existing systems for the storage and exchange of drawings. The most efficient way to incorporate this facility within the I&C Hub is to operate the I&C Hub in parallel with a drawing store and to reference drawings from within the I&C Hub.

Taking a longer term view; the drawings may be used to present the data held within the I&C Hub. Object oriented drawings comprise objects (windows, doors, columns, beams) that are portrayed on the drawing. They are defined by there geometry and may be cut or pasted on the drawing. The data set for each object comprises; an object name, shape, configuration and dimensions. The data set for an object may also contain other information that appears in a text box adjacent to the drawn object when requested (typically on the click of a mouse). This could simply be a part number or details of the supplier but it may also be the information developed in the I&C Hub. For instance; service life, exposure category of a window, security category of a door or type of safety glass in a window.

7.2.4 Response to the need for rapid and timely access to the information

The response to the questionnaire shows that the main problems with accessing information are the time scales and pressure of work under which people have to operate. A further problem is that of conflicting information.

A feature of the I&C Hub is the way in which responsibility for providing information is allocated to the relevant individuals depending on the form of contract. Clearly use of the I&C Hub will not overcome the existence of conflicting information within a project. A useful facility within the I&C Hub would be the ability to question the provider of a piece of data by an e-mail facility embedded in the I&C Hub.

Similarly, if information has not been input to the I&C Hub it would be a useful facility to be able to request that the information is input. Again this could be done by an embedded e-mail facility.

The very use of the I&C Hub should of course remove some of the time pressures in obtaining information. Most of the external technical resources required on a project would be readily available within the I&C Hub obviating the need to track down external documents. If any parties wished to use information external to the project they should either import it into the I&C Hub or provide links to it. An ability to introduce project specific links to external resources would be a useful facility within the I&C Hub.

7.2.5 An integration of functions

The response to the questionnaire shows that qualification and training opportunities of the practitioners in the industry are at an insufficient level. This highlights the potential risk that the ICDM and its contents may be misunderstood and misused. At the same time, the response to the questionnaire also shows the construction industry still has a long way to go to make the best use of ICT. These are significant barriers of implementing the ICDM.

To overcome them, the I&C Hub needs to perform extra functions of providing an independent training programme for the participants, promoting a relevant ICT facility for the coordination of the supply chain, and decision making within projects, besides offering an integrated information source, an interactive knowledge base and communication platform.

It has previously been discussed that a third party can take the roles of training provider and ICT promoter, and will have the advantage to do them. However, it is difficult if they become obligatory, especially with limited technical and financial resources. In addition, intra-project coordination is another challenging job. An ideal means is to train the decision-making group with the representatives from all parties involved at the beginning of a specific project. This should be tested with pilot projects in future research.

Only if the I&C Hub works in a comprehensive way with an integration of functions, will the impact of the ICDM be optimised.

The discussion above caused the author to detail the framework of the I&C Hub, described in section 5.4.4, which separated the information relevant to a project into intra-project level and extra-project level. From the results of the survey and a better understanding of the function of the I&C Hub within a project, enhanced contents and functionality required in the I&C Hub have been shown in Table 7.1.

In section 5.4, a model for the ICDM was developed and illustrated in Figure 5.6. The incorporation of company specific technical data and access to project specific external resources has to be appropriately integrated into this proposed I&C Hub. Figure 7.1 shows how this would be arranged. External resources are simply referenced from the I&C Hub. Company specific technical data has to be integrated with industry wide data within the database. Company specific technical data may be additional to industry wide data or may supplement it. For instance, the use of monolithic glass may be broadly acceptable within the industry but may not be acceptable to a particular company. It would be necessary for them to be able, within the ICDM to show a preference or absolute requirement for the use of laminated glass in a particular situation.

I&C Hub	Contents of information	Functions and roles
Intra-project level	Drawings and integrated project information details, such as design life, construction environment and component specific information.	Data organiser and manager; Training and consultancy; Embedded email system; Request information from external sources.
Extra-project Level	Public information, semi-public information and documents such as Building Regulations, British Standards, and other specific standards or guidance including ASTM , ISO, CWCT, etc.; Company specific technical data; Links to external information sources.	Information filter; Databases developer, Training provider; ICT promoter; Interface to external resources.

Table 7.1 The Integrated information and functions of the I&C Hub

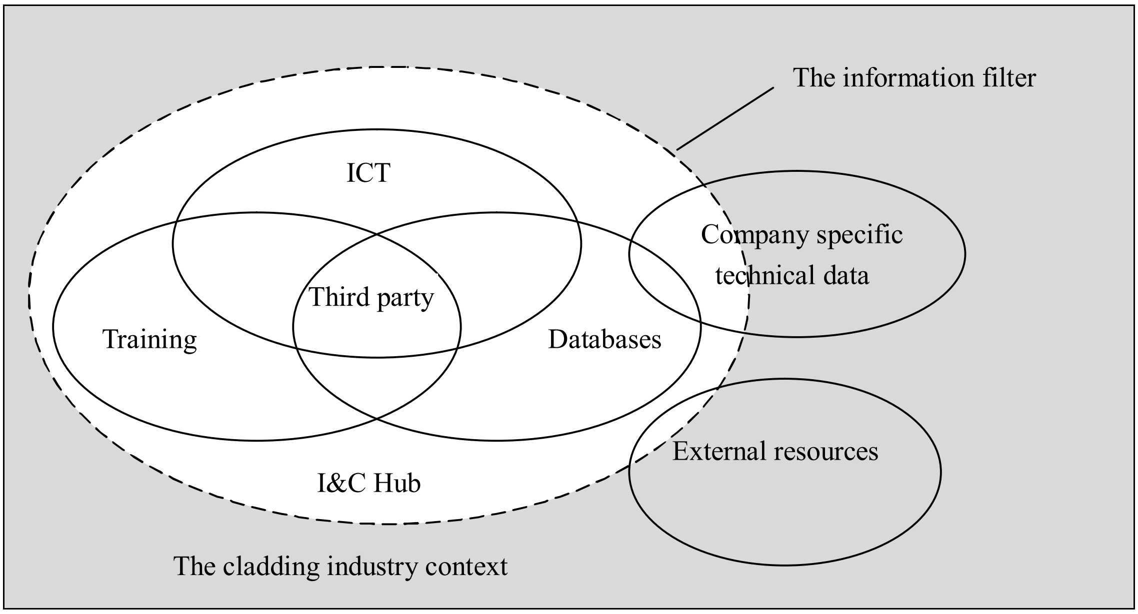


Figure 7.1 The elements of the modified I&C Hub

The basic modules of the I&C Hub include databases, ICT facilities and a training function. The three elements are managed by an industry-level third party and need to work closely to support the operation of the Hub. The Hub is open to the industry and companies, while the information will be filtered before it is made available. Companies can customise the database they access within the ICDM to comprise some industry wide data and also their company specific data. Similarly, companies can now customise the links to external resources. Removing links to unacceptable sources of information and removing links not relevant to a project, for instance British or American Standards.

7.3 Information flow

The study on glass selection in chapter 5 showed the complex nature of the information flow. The original ICDM envisaged information flowing from the client or specifier to decision makers in the main contractor and specialist contractors. This section describes the necessary flows and modifications to the original ICDM.

Within the ICDM， information flows between parties. This may be ‘pushed’ or ‘pulled’. To avoid overloading participants and obscuring information, intra-project information can be categorised into three groups: core, secondary and erratic information.

Core information is relevant to all aspects of the project and includes;

- Environmental data, such as wind and rain
- Design life
- Service environment, such as vandalism and impact
- Heath and safety

- Environmental impact

This type of information is provided by the client, architect, structural engineer, and main contractor. Experienced repeat clients will normally determine the criteria for their projects, while less experienced clients may delegate this to the architect. This information should be entered at an early stage. For sure it will be 'pulled'/requested at an early stage. This information always travels down the supply chain.

Secondary information is not explicit in the performance requirements of the client but required for each party to undertake their design. This includes structural movement, U-value, g-value, and so on. This is provided by the architect, structural engineer, service engineer, main contractor, or specialist contractor. This information general travels horizontally – (up, across and down) the supply chain.

The study of the glass supply chain showed that a third category of information is necessary. This may generally be described as erratic or ad hoc information. In general it travels up the supply chain or horizontally. It includes caveats and cautions associated with particular materials and design solutions, and may detail pre-requisites for the use of certain materials or methods of working. For instance, self-cleaning glass may preclude the use of silicone gaskets or seals; some combinations of metals or metal and stone have to be prohibited; and warranties may not be available for some uses of materials.

A finding from the glass study was the need to know what sub-optimal design may be acceptable and what constraints are negotiable. It would be useful to show not only the data and who provided it but also the reason. For instance, is the blue colour of the glass purely an architect decision, or is it a planning consideration to match an adjacent building, or to satisfy the planners in some other way? Adding a further tag to the data showing whether the requirement is an absolute requirement, an upper bound limit, lower band limit, or simply a desire would facilitate the evaluation and discussion of sub-optimal solutions. This grey data is always present in face-to-face discussions and is an important layer overlying the black-and-white facts. It is important to try and replicate this within the ICDM.

7.4 Evaluation of the enhanced ICDM

After modifying the ICDM, an evaluation on the model was carried out in a discussion with members of the Society of Facade Engineers (SFE). The participants of the meeting were predominantly senior consultants in engineering companies.

The ICDM was described to the SFE meeting by the author. Comments were sought on the feasibility of the proposed ICDM and its relevance/advantages for the specification/design process.

The feedback from industry can be summarised in the following points:

1. The ICDM is feasible for small and simple projects.

2. The ICDM would deliver a building that met specification. However, there are many solutions that meet the specification. All of these have risk associated with them (risk of non-performance, risk of poor assembly, and risk of premature failure). This approach cannot handle the risk-cost balance.

   a) Risk-cost balance could be considered at tender review stage.
   b) Post-tender decisions also affect risk-cost balance.
   c) It is important that tenderers understand the client view of risk-cost balance pre-tender.
   d) It would work for smaller-simpler jobs where the Client does not appreciate risk-cost balance or risks are comparatively small, e.g. a small part of a project such as an entrance screen.

3. In addition to the risk-cost balance there is a quality-cost balance. This was identified in the glass supply chain study described in Chapter 5. Reflecting on the comments above,

   a) Quality-cost balance could be considered at the tender-review stage.
   b) It is important that tenderers understand the client view of quality and cost.

c) The ICDM would work for smaller-simpler jobs comprising mainly standard products and components, for which quality is not discussed at project level.

4. The functionality of the software and outcomes will only be as good as the users of the package. Users have very different knowledge and competencies depending on whether they are involved in;

- Domestic architecture
- Low rise and simple buildings
- High rise or complex buildings

5. There was a concern over ‘dumbing-down’. Users may be led to believe that cladding specification requires nothing more than the ‘ticking of boxes’ rather than complex informed decision making.

6. There was a strongly supported suggestion that the ICDM is a good framework for providing guidance and information such as standards but that it should be demanding of the specifier and make them think. They should question any decision and not simply ‘tick the box’.

7. Such an information framework would compel specifiers to detail the full scope of performance for the wall.

8. Self-evidently the software is only good if it is reliable. Questions were asked about the robustness of the software and how it would be maintained.

9. There will still be a need to review interface details and detailed design.

The comments from the SFE meeting are very valuable for the current positioning and further development of the ICDM. These points revealed that these senior practitioners in the industry recognised the feasibility and functionality of the ICDM within some boundaries.

The views expressed also contained a number of other key concerns from practice.

In fact, small and straightforward projects may have higher failure rates than complex and large ones, because of the shortage of skills and resources, or the lack of application of them, Figure 7.2. This implies that the ICDM could initially be implemented to manage small and straightforward projects. At the same time, the knowledge base within the ICDM could be used to provide supporting information to large and complex projects with its knowledge base, Figure 7.2. After further development and gaining the confidence from the industry, the ICDM may handle more complex situations in practice.

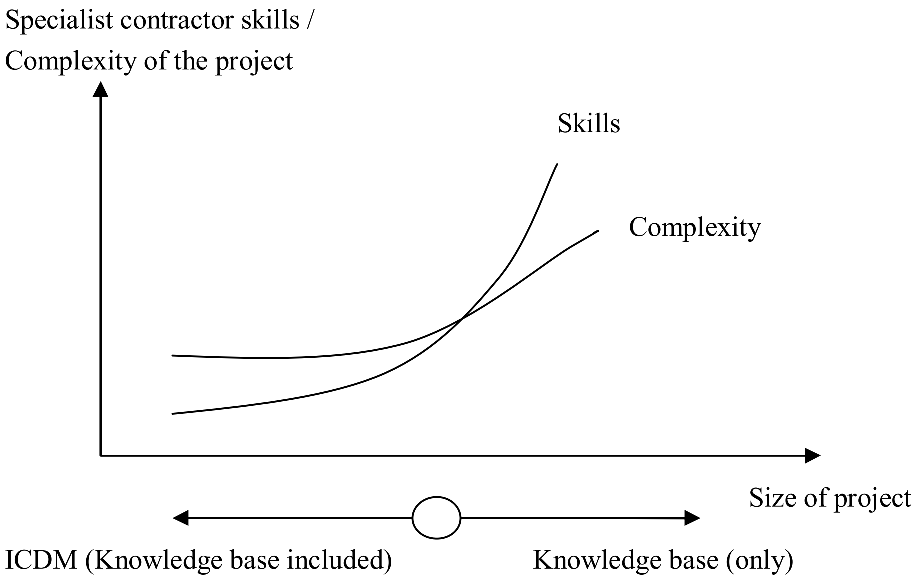


Figure 7.2 The start point of using ICDM

7.5 Summary

Responding to the data collected and analysis of the results presented in Chapter 6, this chapter proposed a number of modifications on the I&C Hub and information flow within

ICDM, and conducted an evaluation on the revised ICDM in a meeting with SFE.

It was realised that the I&C Hub needed to have an integration of functions to enhance its practicality and fulfil the requirements from the industry. The information flow in the ICDM was also re-considered and grouped to mirror practice. The evaluation from the SFE meeting confirmed the feasibility of the ICDM in small and straightforward projects but suggested further development of the model, especially in real cases, was essential to convince the industry to use it on larger and more complex projects. It may not be possible to handle the cost-risk and cost-quality decision-making involved on the most complex and demanding projects.

Chapter 8 Conclusions and Future Work

8.1 Overview

This research is an exploratory research. The aim of this research was to study the cladding design and procurement process, in particular the decision making process. It was hoped to develop an integrated decision making mechanism within the context of the cladding supply chain.

The materials and solutions of cladding are becoming increasingly more complex and the knowledge for decision-making is distributed in different participants of the supply chain. This produces a need for inter-organisational co-operation in decision making.

There is limited academic literature relating to supply chain management and decision making within the cladding sector. Therefore, the author used a wider source for the literature survey. The relevant research projects on cladding, recent management development in the construction industry and automotive industry, as well as decision making theories, have been reviewed. It was identified that information supply and communication were the key factors of informed decision making; however, they are also the weaknesses of the construction industry. At the same time, the development of information technology provides improved methods for managing and communicating information. It was found that the industry needs better collaboration and there was a lack of integrated decision-making mechanisms at industry level.

The early exploration started from programming on-line software to investigate the feasibility of using a project-based IT platform in the communication and decision-making process within the cladding sector. It was established that software and databases to handle the flow of information between different parties involved in a construction project can be developed. Similar facilities have been developed in other industries and a model for the communication process is given in Chapter 5. However, in the filed of facade engineering, some judgements are subjective, for instance appearance, and it is necessary to convey information that is not simply a numerical or logical value. The software approach explored in Chapter 5 is not therefore a total approach to communication and it will sometimes be necessary to 'step outside' the software, particular on complex or prestigious projects, and for example view samples of products. It is also the case that most solutions in facade engineering are suboptimal and that some performance requirements will be sacrificed in the final design. The software approach explored in Chapter 5 should be extended to give a weighting (importance) to each requirement (data element).

At the same time, a further investigation in the automotive industry, which was perceived to perform better than the construction industry, was carried out to gain the experience and lessons learned there. It was noticed that an industry level third party could be able to act as a 'hub' to facilitate information supply and communication. Therefore, a conceptual idea of the Integrated Communication and Decision-making Model (ICDM), centring around an Information and Communication Hub (I&C Hub), was proposed. This conceptual model was the base for further research and a survey was used to test the concept.

A questionnaire survey was the central feature of the survey process, and a number of conferences, industry meetings and informal interviews provided in-depth understanding of the industry, especially on the aspects of communication and the decision-making process. The early interviews and information delivered by industry meetings raised awareness again regarding the issue of information sources. Therefore, the questionnaire was designed to examine the information sources that would lead to the acceptance of third party involvement in project communication. This is critical to the success of the ICDM.

After analysing the results of the questionnaire, there are five main findings as follows:

- Currently, different parties rely on various types of information sources, and the formality of, and QA procedures applied to, information sources are inadequate.
- The majority of the participants in the industry frequently experience difficulties of

accessing information.

- There are too few qualified practitioners and training opportunities for practitioners in the cladding industry are limited.
- ICT facilities have been widely used in the construction industry, but there is still a large potential for improvement.
- An industry level third party could be well accepted by the cladding industry, especially as an independent information source, knowledge base and training provider.

Revisiting the early concept for the ICDM with these findings and early understanding gained from literature review, interviews and industry meetings, the need for and potential feasibility of the ICDM were confirmed.

The findings also implied some challenges in implementing the ICDM. Responding to the results of the survey, a number of modifications were carefully considered and outlined in chapter seven.

This chapter concludes the thesis, highlighting the contributions, implications and limitations of the research. A cluster of future work is recommended.

8.2 Contributions of this study

This research provided a clearer understanding of the needs to communicate and a framework in which to communicate.

The information sources used in the cladding supply chain were clarified in this study. Five main findings relating to information sources and communication in the cladding industry were gained from the results of the questionnaire survey. The formality of and QA procedures applied upon information sources are inadequate, as well as the practitioners frequently experience difficulties in accessing information in the industry. These issues may considerably impact decision making process and results. Efficient communication mechanisms are needed. In addition, from the informal interview, it appears that these interviewees reflected on the way they communicate. It also made significant contribution to the literature of this area.

A conceptual mechanism for integrated communication and decision-making (ICDM) within the context of cladding supply chain, was preliminarily developed and partially validated. Its core part, a two level I&C Hub run by a third party, provides an integrated information source and communication platform. The necessity and feasibility have been preliminarily examined. It is also a framework to drive technical thinking; to identify technical needs; and to promote uptake of technical development.

8.3 Limitations and challenges

8.3.1 Limitations of the research

There are two main limitations that need to be addressed regarding this study. The first limitation concerns the sample of the research. The size of sample was relatively small for the industry and there was a shortage in respondents from clients and main contractors. At the same time, most of the interviewees and respondents hold senior positions, which may provide more in-depth views but opinions from junior practitioners are also valuable for the research.

Another limitation of the research is that, due to the author's limited resources and time, the ICDM was not completely validated, especially at intra-project level in this research. The questionnaire was employed to test information sources and third party acceptance of the industry. However, the conceptual model can only be fully examined when the model is applied in real cases where sufficient information and sources are available to launch software.

8.3.2 Challenges for implementation

The integrated communication and decision-making model may bring many benefits for the cladding industry, as described in chapter five; however, transformation of the industry and companies is never straightforward, especially in traditional companies. The direct challenges of implementing the ICDM and establishing the I&C Hub have been described and explained in 6.5.2, as follows:

- The qualification of the practitioners
- The adequacy of the ICT facilities
- Customs of the industry
- Business model for the I&C Hub
- Competence of the third party

Theoretically, under the conceptual model, the parties involved could work in a more collaborative way by clarifying responsibilities and rights; and the cooperation process can be made more robust and fluent with contemporary IT facilities and supply chain management expertise. However, this transformation requires a series of changes, including re-structuring of the communication process, re-orienting participants, providing IT training and facilities in a relatively harsh environment of the traditional industry. Many detailed tasks need to be investigated further to optimise the process.

Nevertheless, these kinds of change will become trends, partly because the industry does not have too many options to manage the increasing complexities and performance requirements. In fact, the construction industry as a whole also faces the realisation that it has to change.

8.4 Recommendations for future work

According to the results and the limitations of this research, many efforts need to be made in future work, including the following:

- Develop the knowledge base in a limited area such as selection of glass. Even in the limited field of glass selection there are still entrenched positions on issues relating to safety such that building designers and glass manufacturers fail to agree on basic technical performance;
- Work with an IT service provider to produce more practical ICT solutions for implementing the integrated communication and decision-making mechanism in pilot projects and conduct case studies;
- Further validation on pilot projects;
- Investigate the feasibility of rolling out the integrated communication and decision-making model across other parts of the construction industry.

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Appendix A Perl scripts

Register.pl

```
#!/usr/local/bin/perl -- -*-perl-*-

print "Content-type: text/html\n\n";
use CGI qw(:standard);
use strict;
use DBI;

my   $dbh   =   DBI->connect('DBI:mysql:PROJsupplychain:mysqlhost.bath.ac.uk',   'abmqd',
                'KeLLw22m3') or die "Cannot connect database: " . DBI->errstr;
# 1.connect to the database

my $fullname=lc(param('fullname'));
my $email=lc(param('email'));
my $groop=lc(param('groop'));
my $user=lc(param('username'));
my $pass=lc(param('password'));
my $question=lc(param('question'));
my $answer=lc(param('answer'));

my $sth = $dbh->prepare(q{
INSERT INTO authen_table (groop, user, password, fullname, email, question, answer)
                VALUES (?, ?, ?, ?, ? ,?, ?)
});
# 2.build a query
# 3.build a statement handle
#   ($groop, $user, $pass, $fullname, $email, $qustion, $answer)

$sth->execute($groop, $user, $pass, $fullname, $email, $question, $answer);
# 4.execute the statement handle

$sth->finish;
$dbh->disconnect;
#               print the web stuff

print           <<"HTML code";

                <html>
                <head>
```

```
<link rel=STYLESHEET href=style.css type=text/css>
<style>
#head {position:absolute; top:0px; left:0px}
#panel {position:absolute; top:57px; left:0px}
#body {position:absolute; top:57px; left:201px}
</style>
</head>
<body text=#000000 bgcolor=#FFFFFF link=#001254 vlink=#551A8B
alink=#FF0000>
<span id=head>
<table CELLPADDING=10 WIDTH=950 HEIGHT=56
BGCOLOR=#CCCCFF>
<tr>
<td VALIGN=CENTER WIDTH=750><b><font face=ARIAL><font
color=#FFFFFF><font size=+0> 
CWCT SUPPLY CHAIN PROJECT</font></font></font></b></td>
<td WIDTH=200>
<div align=right><img
SRC=http://www.bath.ac.uk/~abmqd/supplychain1/images/smlogo.gif></di
v>
</td>
</tr>
</table>
</span><span id=panel>
<table BORDER=0 CELLSPACING=0 CELLPADDING=0 COLS=1
WIDTH=180 HEIGHT=550 BGCOLOR=#E0E0FF>
<tr>
<td VALIGN=TOP>
<table BORDER=0 CELLSPACING=0 CELLPADDING=0 WIDTH=180
BGCOLOR=#E0E0FF>
<tr>
<td WIDTH=10> </td>
<td WIDTH=70> </td>
<td WIDTH=100><font face=Arial><font
size=-1> </font></font></td>
</tr>
<tr>
<td> </td>
<td><b><font face=Arial><font color=#FF0000><font
size=-1>Congratulations! Registered
successfully!</font></font></font></b></td>
<td> </td>
</tr>
<tr>
```

```
<td> </td>
<td COLSPAN=2><b><font face=Arial><font color=#FF0000><font
size=-1>
```

HTML code

```
print "</font></font></font></b></td>
</tr><tr>
<td> </td>
<td><b><font face=Arial><font color=#000000><font
size=-1> </font></font></font></b></td>
<td>  </td>
</tr><tr>
<td> </td>
<td COLSPAN=2><b><font face=Arial><font color=#FF0000><font
size=-1>As
";
print $groop;
print "</font></font></font></b></td>
</tr><tr>
<td> </td>
<td> </td>
<td> </td>
</tr><tr>
<td> </td>
<td VALIGN=TOP COLSPAN=2>
<p><b><font face=Arial><font color=#FF00FF><font size=-1>Useful
links:</font></font></font></p>
<p><b><font face=Arial><font color=#FF00FF><font size=-1><a
href='http://www.bath.ac.uk/~abmqd/standard'>
CWCT standards database</a></font></font></font></p>
</td>
</tr></table></td></tr></table>
</span>

<span id=body>
<table BORDER=0 CELLSPACING=0 CELLPADDING=5 WIDTH=599
BGCOLOR=#FFFFFF>
<tr>
<td><b><font face=Arial><font size=-1>Would you like sign in
now?</font></font></b>
<br> <br> 
<table BORDER=0 CELLSPACING=0 CELLPADDING=0 WIDTH=400>
<tr>
```

```
                <td WIDTH=100>
                <center></center>
                </td>
                <td WIDTH=300></td>
                </tr>
";

print           "<tr><td></td><td> </td></tr><tr><td></td>
                <td><a href=http://www.bath.ac.uk/~abmqd/supplychain2/home.htm> <img
                src=http://www.bath.ac.uk/~abmqd/supplychain1/images/continue.gif></a>
                </td>
                </tr></table>
                <p> </td></tr></table></span></body></html>
";
```

Login.pl

```
#!/usr/local/bin/perl -- -*-perl-*-

use CGI qw(:standard);

use Carp;
use DBI;

print		"Content-type: text/html\n\n
";

#		print the web stuff

print		<<"HTML code";

		<html>
		<head>
		<link rel=STYLESHEET href=style.css type=text/css>
		<style>
		#head {position:absolute; top:0px; left:0px}
		#panel {position:absolute; top:57px; left:0px}
		#body {position:absolute; top:57px; left:201px}
		</style>
		</head>
		<body text=#000000 bgcolor=#FFFFFF link=#001254 vlink=#551A8B
		alink=#FF0000>
		<span id=head>
		<table CELLPADDING=10 WIDTH=950 HEIGHT=56
		BGCOLOR=#CCCCFF>
		<tr>
		<td VALIGN=CENTER WIDTH=750><b><font face=ARIAL><font
		color=#FFFFFF><font size=+0> 
		CWCT SUPPLY CHAIN PROJECT</font></font></font></b></td>
		<td WIDTH=200>
		<div align=right><img
		SRC=http://www.bath.ac.uk/~abmqd/supplychain1/images/smlogo.gif></di
		v>
		</td>
		</tr>
		</table>
		</span><span id=panel>
		<table BORDER=0 CELLSPACING=0 CELLPADDING=0 COLS=1
		WIDTH=180 HEIGHT=550 BGCOLOR=#E0E0FF>
```

```
<tr>
<td VALIGN=TOP>
<table BORDER=0 CELLSPACING=0 CELLPADDING=0 WIDTH=180
BGCOLOR=#E0E0FF>
<tr>
<td WIDTH=10> </td>
<td WIDTH=70> </td>
<td WIDTH=100><font face=Arial><font
size=-1> </font></font></td>
</tr>
<tr>
<td> </td>
<td><b><font face=Arial><font color=#000000><font
size=-1>Welcome:</font></font></font></b></td>
<td> </td>
</tr>
<tr>
<td> </td>
<td COLSPAN=2><b><font face=Arial><font color=#FF0000><font
size=-1>
```

HTML code

```
#		Check passwords and allow/deny entry



my $groop=lc(param('groop'));
my $user=lc(param('username'));
my $pass=lc(param('password'));

my $do="no";


my $dbh = DBI->connect('DBI:mysql:PROJsupplychain:mysqlhost.bath.ac.uk', 'abmqd',
		'KeLLw22m3') or die "Cannot connect database: " . DBI->errstr;
# 1.connect to your database

my $query = "SELECT * FROM authen_table";
# 2.build a query

my $sth =$dbh->prepare($query);
# 3.build a statement handle
```

```
$sth->execute() or die "error: " . $sth->errstr;
# 4.execute the statement handle

while (my @row = $sth->fetchrow_array){

            if ($user eq lc($row [2]) and $pass eq lc($row[3]) and $groop eq
            lc($row[1]) )
            {
            $do="yes";
            $fullname=$row[4];
            }
}

if ($do eq "yes")
{

#           print the project page

$fullname=uc(substr($fullname,0,1)).substr($fullname,1);
$user=uc(substr($user,0,1)).substr($user,1);
$groop=uc(substr($groop,0,1)).substr($groop,1);

print $user;

$user="^".$user;

print       "</font></font></font></b></td>
            </tr><tr>
            <td> </td>
            <td><b><font face=Arial><font color=#000000><font
            size=-1> </font></font></font></b></td>
            <td>  </td>
            </tr><tr>
            <td> </td>
            <td COLSPAN=2><b><font face=Arial><font color=#FF0000><font
            size=-1>As
";
print       $groop;
print       "</font></font></font></b></td>
            </tr><tr>
            <td> </td>
            <td> </td>
            <td> </td>
            </tr><tr>
```

```
<td> </td>
<td VALIGN=TOP COLSPAN=2>
<p><b><font face=Arial><font color=#FF00FF><font size=-1>Useful
links:</font></font></font></p>
<p><b><font face=Arial><font color=#FF00FF><font size=-1><a
href='http://www.bath.ac.uk/~abmqd/standard'>
CWCT standards database</a></font></font></font></p>
</td>
</tr></table></td></tr></table>
</span>


<form action=http://www.bath.ac.uk/~abmqd/cgi/spc/project.pl
method=post>
<input type=hidden name=username value=
";
print $user;
print "><input type=hidden name=password value=
";
print $pass;
print "><input type=hidden name=firstname value=
";
print $fullname;
print "><input type=hidden name=groop value=
";
print $groop;

print ">
<span id=body>
<table BORDER=0 CELLSPACING=0 CELLPADDING=5 WIDTH=599
BGCOLOR=#FFFFFF>
<tr>
<td><b><font face=Arial><font size=-1>Which project do you wish to
work on?</font></font></b>
<br> <br> 
<table BORDER=0 CELLSPACING=0 CELLPADDING=0 WIDTH=400>
<tr>
<td WIDTH=100>
<center></center>
</td>
<td WIDTH=300></td>
</tr>
";
```

```
open                (PROJ, 'projects.txt');
while(my $name = <PROJ>)
{
                    chomp $name;$user="^".$user;
                    my @word=split /%/, $name;

my $value="value='".$word[1]."'";
print               "<tr><td>
                    <center><input type=radio name=project
";
print               $value;
print               "></center>
                    </td><td><font face=arial><font size=-1>
";
print               $word[1];
print               "</font></font></td></tr>
";

}
close PROJ;


print               "<tr><td></td><td> </td></tr><tr><td></td>
                    <td><input                                  type=image
                    src=http://www.bath.ac.uk/~abmqd/supplychain1/images/continue.gif
                    border=0 name=submit value=submit></td>
                    </tr></table>
                    <p> </td></tr></table></span></body></html>
";

                    }

else

                    {

#                   print the refusal page

print               " </td></tr>
                    <tr><td> </td>
                    <td    COLSPAN=2><b><font    face=Arial><font    color=#FF0000><font
                    size=-1> </font></font></font></b></td>
                    </tr><tr>
                    <td><b> </b></td>
```

```
<td> </td>
<td> </td>
</tr><tr><td> </td>
<td><b><font face=Arial><font color=#000000><font
size=-1> </font></font></font></b></td>
<td>  </td>
</tr><tr>
<td> </td>
<td COLSPAN=2><b><font face=Arial><font color=#FF0000><font
size=-1> </font></font></font></b></td>
</tr><tr><td> </td>
<td> </td>
<td> </td>
</tr><tr>
<td> </td>
<td VALIGN=TOP COLSPAN=2> </td>
</tr></table></td></tr></table>
</span><span id=body>
<table BORDER=0 CELLSPACING=0 CELLPADDING=5 WIDTH=599
BGCOLOR=#FFFFFF>
<tr>
<td><b><font face=Arial><font size=-1>Invalid password and or
username</font></font></b>
<p> </td></tr></table>
</span></body></html>
";
}

close IN;
```

Stage1.pl

```
#!/usr/local/bin/perl -- -*-perl-*-

print "Content-type: text/html\n\n";

use CGI qw(:standard);

use strict;

use DBI;

my $dbh = DBI->connect('DBI:mysql:PROJsupplychain:mysqlhost.bath.ac.uk', 'abmqd',
        'KeLLw22m3') or die "Cannot connect database: " . DBI->errstr;
# 1.connect to your database

my $query = "SELECT * FROM authen_table";
# 2.build a query

my $sth =$dbh->prepare($query);
# 3.build a statement handle

$sth->execute();
# 4.execute the statement handle

print "Two typical approacheds to fetch data with different aims<br><hr><hr>\n";

print "(A)Fetch data with fetchrow_arrayref(): quick way and achieve refference number
        <br><hr> \n";
print "(1)Row Refferneces: <hr>\n";
while (my $row = $sth->fetchrow_arrayref) {
    print  "$row\n";
}
# 5.retrieve and process the results--by fetchrow_arrayref() in a (while) loop
#$row is the a refference to a array (eg. ARRAY(0x15357c)) ,
#so we use "@$row" to retrieve the array of fields the reference $row
print "<hr>";

print "(2)Rows without table sign: <hr>\n";
$sth->execute();
while (my $row = $sth->fetchrow_arrayref) {
    print  "@$row\n";
}
#"$sth->execute();" is needed again, select once when fetch once.
```

```
#otherwise, "DBD::mysql::st fetchrow_arrayref failed: fetch() without execute()
print "<hr>";

print "(3)Rows with table sign:--only shown under Unix but not IE <hr>\n";
$sth->execute();
while (my $row = $sth->fetchrow_arrayref) {
    print   join("\t", @$row), "\n";
}
#Note: while loop + @$row syntax is the typical way for fectch!!!
print "<hr><hr>";

print "(B)Fetch data with fetchrow_array() instead of fetchrow_arrayref(): suitable for making
                    HTML table <br><hr> \n";
#It is another typical way:   while loop + @row + foreach loop + $field(@row)!!!

print "(1)Rows without table sign: <hr>\n";
$sth->execute();
while (my @row1 = $sth->fetchrow_array){
  print "@row1\n";
}
print "<hr>";

#Note: Never forget the "my" and changing the @row to @row1!!!

print "(2)Rows with table sign: same as (A)(3)<hr>\n";
$sth->execute();
while (my @row1 = $sth->fetchrow_array){
  print join("\t", @row1), "\n";
}
print "<hr>";

print "(3)Fields without table sign: --different from (A)(2)&(B)(1)--no space between two
                    fields<hr>\n";
$sth->execute();
while (my @row1 = $sth->fetchrow_array){
  foreach my $field(@row1){
    print "$field";
  }
  print "\n";
}
print "<hr>";

print "(4)Fields with table sign: useless!---table sign only work for row under Unix -- so same
                    as (B)(3)<hr>\n";
```

```
$sth->execute();
while (my @row1 = $sth->fetchrow_array){
  foreach my $field(@row1){
     print join("\t", $field);
  }
  print "\n";
}
print "<hr>";

print "(5)Fields with HTML table element-- that is why use the fields to be printed
              here<hr>\n";
$sth->execute();
print "<html><body><h1>Users' personel details: Authen_table</h1>";
print "<table>\n";
print
              "<tr><th>ID</th><th>Group</th><th>Username</th><th>Password</th><
              th>Fullname</th><th>E-mail address</th><th>Secret
              question</th><th>Answer</th><th>Creation</th><th>Modified</th><th>P
              W_timestamp</th><th>Key</th>\n";

while (my @row1 = $sth->fetchrow_array){
  print "<tr>";
  foreach my $field(@row1){
     print "<td>$field</td>";
  }
  print "</tr>\n";
}
print "</table>\n";

print "</body><html>";

print "<hr>";

$sth->finish;
$dbh->disconnect;
```

Address1.pl

```
#!/usr/local/bin/perl -- -*-perl-*-

print "Content-type: text/html\n\n";

use DBI;

my $dbh = DBI->connect('DBI:mysql:PROJsupplychain:mysqlhost.bath.ac.uk:3306', 'abmqd',
                    'KeLLw22m3') or die "can't connect db: " . DBI->errstr;

print "insert some records\n";
my $sth = $dbh->prepare(q{
INSERT INTO address (id, name,email,telephone) VALUES (?, ?, ?, ?)
});

print "input, press Entre when finish:";
while ($inputdata =<>) {
chop $inputdata;
last unless($inputdata);
my ($id, $name,$email, $tel) = split( /,/, $inputdata);
$sth->execute($id, $name, $email,$tel)
}
# $dbh->commit;

print "print EMAIL and telephone no. according name input\n";
my $sth = $dbh->prepare('SELECT * FROM address WHERE name=?')
or die $dbh->errstr;
print "input name, press Entre when finish:";
while ($inputname =<>) {
my @data;
chomp $inputname;
last unless($inputname);
$sth->execute($inputname) or die "error: " . $sth->errstr;
while (@data = $sth->fetchrow_array()) {
print "Email:$data[2]\t Telephone:$data[3]\n";
}
}

$dbh->disconnect
```

Appendix B Web-based communication software

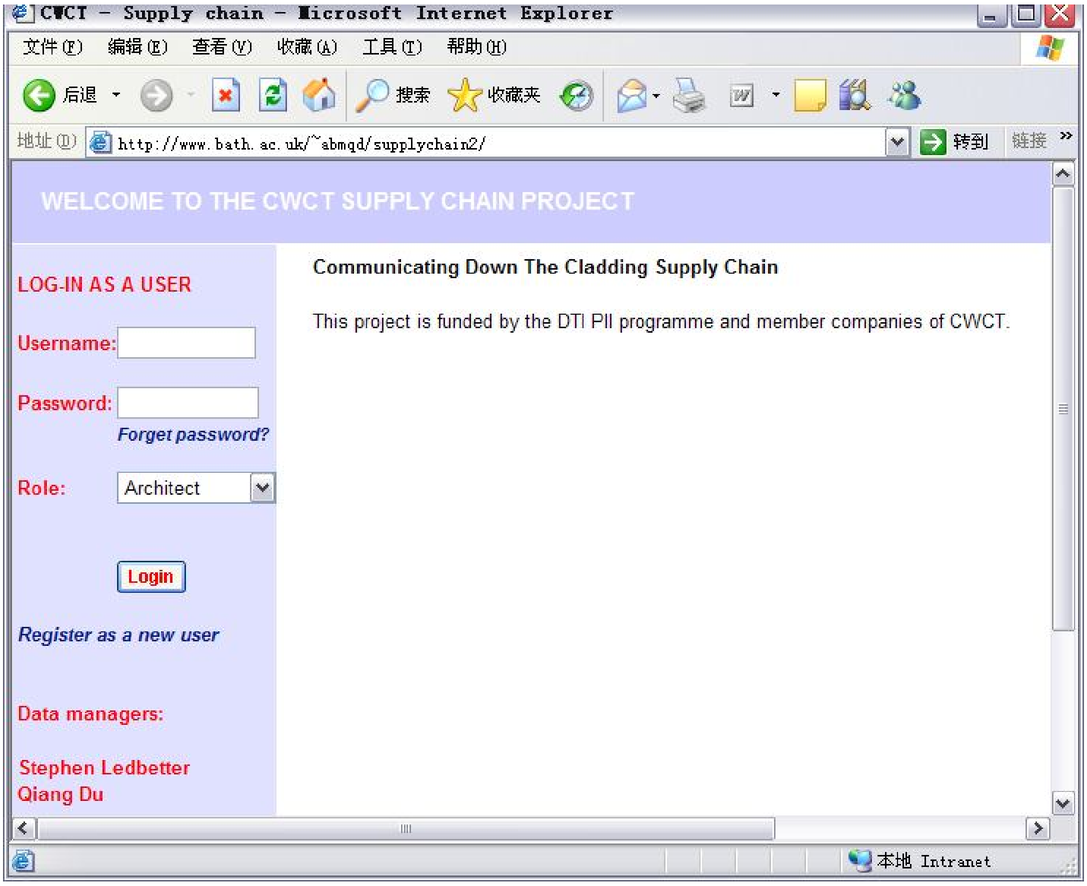

Figure 1 The homepage

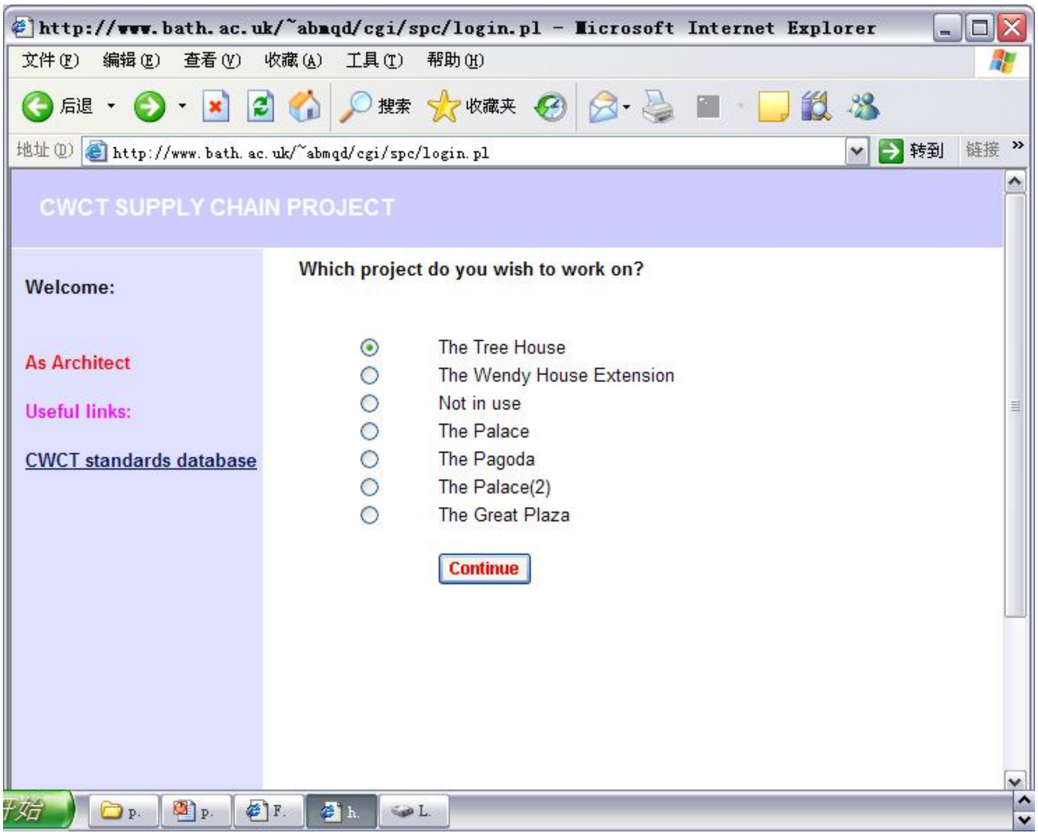

Figure 2 Which project do you work on?

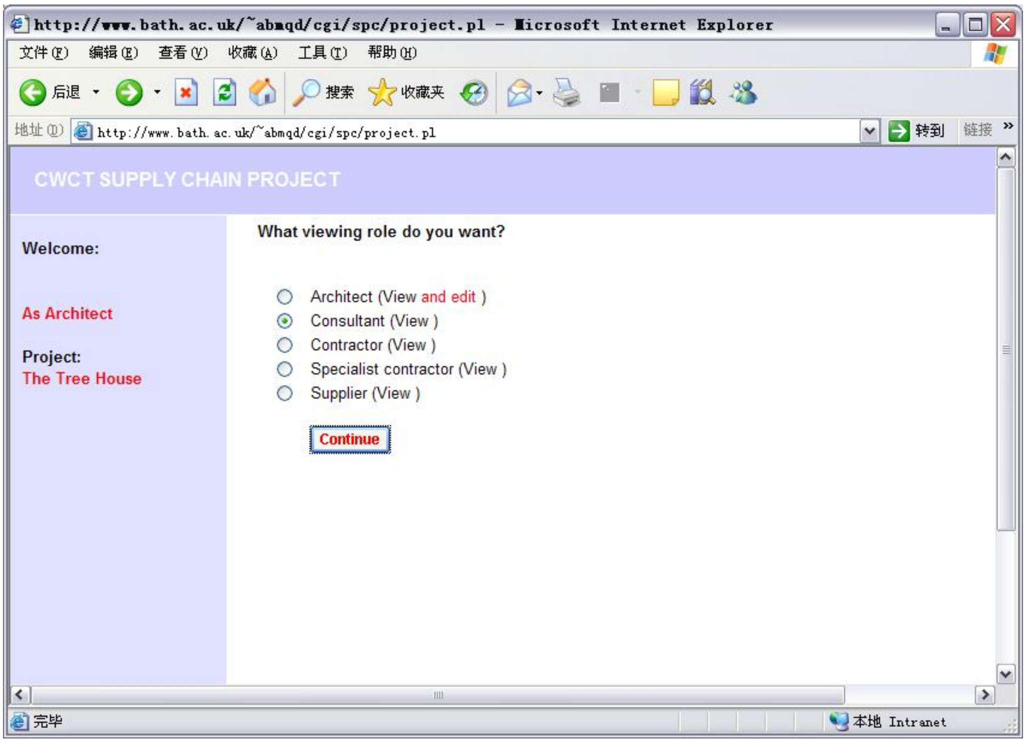

Figure 3 Which role do you want?

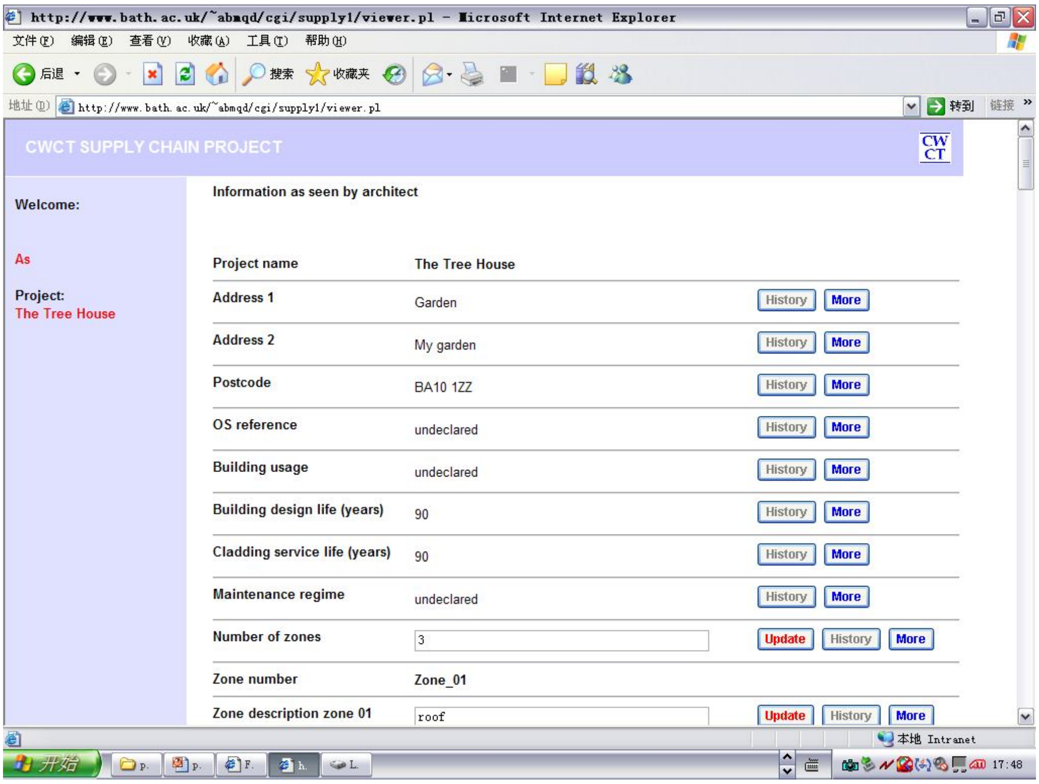

Figure 4 Basic project information

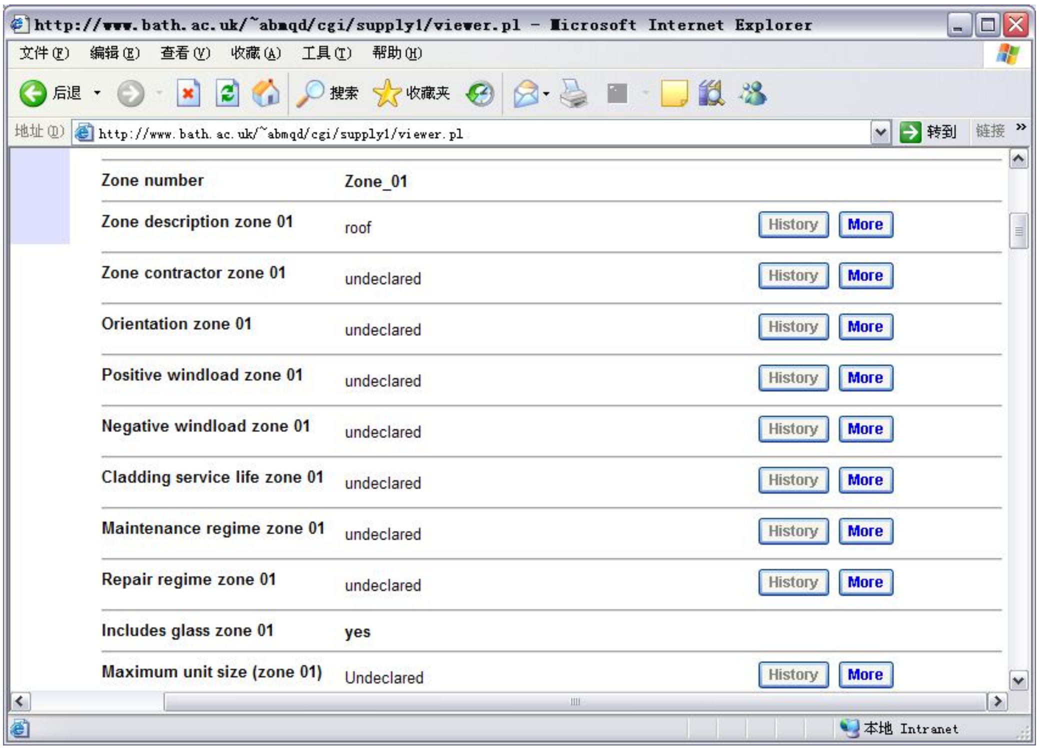

Figure 5 Information of zone 01

Appendix C Examples of interview transcriptions

Example 1: Interview with the Director of a facade engineering consultancy

I: The author

D: The interviewee

I What's the business context you find yourself in?

D Basically we provide project-specific consultancy and systems design services for building facades. Our clients mainly include construction clients, architects, contractors, as well as manufacturers. We are currently designing system profiles for a famous aluminium systems company. We are very proud of it. We can also do structural and thermal simulation and analysis.

I What do you think about the current communication in cladding industry?

D Sometimes it is quite annoying. For example, a cladding sub-contractor asked us to do the thermal analysis to prove their solution/design, but they didn't supply sufficient material information until a few months later.

To simulate the thermal performance specific to that case, we required the material properties of the curtain walling and ceiling. However, they only work on the curtain walling and had no any information about the ceiling. They went to the main contractor, and then main contractor turned to the architect. The architect doubted why the curtain walling contractor needed information about the properties of ceiling materials, and was quite conservative about the information.

Because it was not that urgent, we mainly communicated by email; therefore, they can response late. It was three months later when we finally got the sufficient information. It wasted time and resources.

I Do you think it needs improvement?

D Certainly, yes. But it is difficult to change the culture of the industry.

I What do you think about ICT facilities in the construction industry, particularly in the cladding sector?

D ICT is critically important in the industry now, for design, simulation, analysis, project management as well as communication. Email has become the most frequently used method (of communication), especially between two companies.

I Do you regularly use the IT platform to share information and communication in projects?

D We don't have intranet in our company though we have our website. But I used some IT platforms developed by main contractors in several big projects. I think it is useful for sharing and transferring information, but for real time communication, we still need email and telephone.

I Have you noticed any third-party involvement in the industry, for intra-project communication?

D Our company is a third party, and often co-ordinate with different types of companies.

I I mean the industry level third party, like CWCT, a non-profit making organisation, involved in the projects.

D Wow, I think the CWCT did very well in summarising the recent technical development and producing quality and process standards, as well as organising industry meetings and training. As you known, we are a member company of the CWCT and have sent a few staff to the MSc course (in Facade Engineering) at Bath University. But I don't know its involvement for specific projects. Maybe sometimes it acted as an arbitrator for disputation.

I Do you go on the CWCT's website regularly?

D The CWCT's website is pretty good. I sometimes download recent technical notes from the member forum. There are also information about recent industry seminar and meetings.

I How do you think about the importance of the communication?

D It is very important. Successful communication is essential for successful projects and benefits every participant.

I Do you think the integrated communication and decision-making strategy is practical for specific projects?

D I am not sure. It depends on how good it is and who should pay for it. In addition, it is quite difficult to find a competent organisation to manage it.

I If there is an online communication hub for specific project, would you like to participate it?

D It depends on how much benefit I can gain and how much do I need to pay for it. If it is free, I can try. But until it is fully proved, I don't want to rely on it. I am afraid that, sometimes, it may make things more complex.

End of interview

Example 2: Interview with the Technical Director of a facade subcontractor

I: The author

T: The interviewee

I Could you briefly introduce your company, please?

T Sure. We are a curtain walling specialist company, providing integrated solutions for building facades, from systems design to on-site installation. We are based in Asia and have strong global presence. The UK office was open in 2002. We did very well so far.

I As an Asia based company, what's your competitive advantages in the UK market?

T We deliver good quality in agreed time but with a relatively low price. Both design and manufacturing are done in Asia. This gives us the advantages in prices. We employed experienced local project managers and engineers to secure the quality complying with the Standards. To save the installation costs, we mainly pick the jobs using unitised systems rather than stick systems, which enables us ship the whole panels from our manufacturing bases located in Asia. In addition, we have a group of outstanding technical experts in our headquarters. They have been involved in many prestigious projects across the world, and the UK office can get technical support from them.

I Have you encountered difficulties during the operation?

T It was especially difficult in the beginning. After a few small projects, we established our image and close relationships with several main contractors. Currently, if these main contractors go to bid projects, they will invite us to work with them together. We have secured our position in their supply chains.

I How do you feel the communication in projects?

D I think communication is commonly difficult for subcontractors. The situation is the same in Asia. The design frequently changes and information is often unclear. The communication between subcontractors is limited and insufficient. If the main contractor input enough effort in interface management, the situation could be better.

The consultants sometimes are difficult to communicate with. Some of them only follow the Standards rather than consider issues in a realistic way. For example, one cladding consultant raised a doubt that the system might have condensation risk and required a simulation analysis. However, the moulds have been made according to the latest design changes. Why didn't they discuss this issue early?

Because we have our own manufacturing facilities, we don't worry too much about the supply of systems. However, we need to purchase glass. Our suppliers can usually provide very economic solutions while meeting the Standards and performance requirements. However, quite a few installed glass panes cracked in one of our recent projects. We tried to claim from the supplier but they just pushed the responsibility to others.

I Do you think there is a need to improve the communication?

D Yes, I think so. The performance requirements and complexity of building facades are going high. The parties really need to work together to resolve the design early and reach the objectives.

I Do you use IT frequently in your business?

T Yes, in design and communication.

I How about IT platform for information sharing?

T Actually, we don’t have a special IT platform to share information. We usually transfer information by email, phone and fax.

I What do you think the role of an industry third party, like the CWCT?

T The industry really needs an organisation like the CWCT, with technical authority and an independent standing point. The CWCT is quite influential in the industry, with its publications, training and other services. For us, the CWCT Standards and Technical Notes provide a valuable guidance. We will have our installers trained with the CWCT’s certification scheme.

I What do you think about the integrated communication and decision-making mechanism?

T It is probably practical, if the service provider have sufficient capabilities and resources. If it is proved that it can provide clearer information and indentified responsibilities, personally, I would probably pay for this service.

I Have you got any suggestion for this strategy?

T There should be a proper business model for this development. Otherwise, it won’t last long. In addition, if you want to develop an interactive IT platform, you probably have to attract the users with some incentive system. It would encourage interaction and contribution from individuals and companies.

End of interview

Appendix D Questionnaire

Resources and communication questionnaire

Please take a few minutes to help CWCT improve it deliverables to it Member's and the wider construction industry. We value your feed back and support as we continuously review the scope of our development work and dissemination of knowledge to the industry.

We undertake not to identify any individuals or companies who complete the questionnaire but may release statistical summaries of the information supplied.

---

1. First name (Optional) ☐

Family name (Optional) ☐

Company name (Optional) ☐

Job title ☐

Member of CWCT ☐

---

2. Company type

☐ Construction client

☐ Architect

☐ Engineer/consultant

☐ Main contractor

☐ Specialist contractor

☐ Manufacturer/Supplier

Other ☐

---

3. Company size

☐ Turnover (£)

or ☐ Employees

---

4. Company base

- ☐ United Kingdom
- ☐ European operating in UK
- ☐ International operating in UK

Operating elsewhere ____________

5. Which of the following in-house resources are available to you?

- ☐ Company library
- ☐ Company intranet
- ☐ In-house specialist
- ☐ Project or section manager
- ☐ Line manager

6. *(If you are a specialist cladding company go to question 9)*
Is there a facade knowledge network in your company?

- ☐ Yes
- ☐ No

7. *(If you answered yes to question 6.)*
Is this a formal network?

- ☐ Yes
- ☐ No

8. *(If you answered yes to question 6.)*
How do you normally access this network?

- ☐ By intranet
- ☐ By e-mail
- ☐ Face to face

9. How often do you use these external sources of information?

Standards	*Often*	☐	☐	☐	☐	☐	*Seldom*
Trade association literature	*Often*	☐	☐	☐	☐	☐	*Seldom*
Manufacturers literature	*Often*	☐	☐	☐	☐	☐	*Seldom*
Manufacturers technical advisory service	*Often*	☐	☐	☐	☐	☐	*Seldom*
Certification schemes (BBA,CWCT...)	*Often*	☐	☐	☐	☐	☐	*Seldom*
Consultants	*Often*	☐	☐	☐	☐	☐	*Seldom*
CWCT	*Often*	☐	☐	☐	☐	☐	*Seldom*

---

10. Which other sources of information do you use?

[ ] *Most often*

[ ]

[ ] *Least often*

---

11. Do you hold a qualification in facade engineering? ☐

In your organisation does anybody other than you

hold a qualification in facade engineering? ☐

---

12. Do you have access to mid-career training (CPD)? ☐

In your organisation does anybody other than you

have access to mid-career training (CPD)? ☐

---

13. *(If you answered yes to question 12)*

Which training providers do you use? [ ] *Most often*

[ ]

[ ] *Least often*

---

14. What, if any, QA procedures are applied to sources of information?

I have open access to information on the internet ☐

There is a corporate filter through an intranet or other interface ☐

Other ☐

Please state other

15. Outside of the facade engineering field what do you believe are good examples of providing technical information?

Source 1

Source 2

Source 3

16. What guidance would you like to access that you are not currently aware of?

Subject 1

Subject 2

Subject 3

17. What Standards do you think should be developed?

Subject 1

Subject 2

Subject 3

18. If you have used an extranet or other IT platform to host project information what did it contain?

Drawings ☐

Specification ☐

Method statements ☐

Technical standards ☐

Supporting technical guidance ☐

Health and safety information ☐

Other

Other

19. If you have used an extranet or other IT platform to host project information what additional information should it have held?

20. To what extent are the following barriers to accessing information when working on a project?

Time scale	*Often*	☐	☐	☐	☐	☐	*Seldom*
Work load	*Often*	☐	☐	☐	☐	☐	*Seldom*
Inability to access sources	*Often*	☐	☐	☐	☐	☐	*Seldom*
Inability to agree sources	*Often*	☐	☐	☐	☐	☐	*Seldom*
Conflicting information	*Often*	☐	☐	☐	☐	☐	*Seldom*

21. What other barriers to accessing information have you experienced?

Barrier 1

Barrier 2

Barrier 3

22. How do you rate the CWCT website?

Technical authority	*Good*	☐	☐	☐	☐	☐	*Poor*
Technical quality	*Good*	☐	☐	☐	☐	☐	*Poor*
Independence	*Good*	☐	☐	☐	☐	☐	*Poor*
Easy to navigate	*Good*	☐	☐	☐	☐	☐	*Poor*
Useful	*Good*	☐	☐	☐	☐	☐	*Poor*

23. What other information would you like to find on the CWCT website?

Information 1 ______

Information 2 ______

Information 3 ______

24. If you have used the CWCT Technical Notes how do you rate them?

Technical authority	*Good*	☐	☐	☐	☐	☐	*Poor*
Technical quality	*Good*	☐	☐	☐	☐	☐	*Poor*
Independence	*Good*	☐	☐	☐	☐	☐	*Poor*
Relevance	*Good*	☐	☐	☐	☐	☐	*Poor*
Easy to understand	*Good*	☐	☐	☐	☐	☐	*Poor*

25. What other CWCT technical notes would you like us to produce?

Topic 1 ______

Topic 2 ______

Topic 3 ______

Appendix E Full results of some questions

Question 5 Which of the following in-house resources are available to you?

Company library

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	4	57.1	3	42.9
	Client	2	66.7	1	33.3
	Engineer/consultant	18	100	0	0
	Main contractor	0	0	5	100
	Manufacturer/supplier	10	83.3	2	16.7
	Specialist contractor	8	47.1	8	47.1
	Total	42	67.7	19	22.3

Descriptive Statistics : Company Library

Company type	N	Minimum	Maximum	Mean	Std. Deviation
Architect	7	1	2	1.43	.535
Client	3	1	2	1.33	.577
Engineer/consultant	18	1	1	1.00	.000
Main contractor	5	2	2	2	.000
Manufacturer / supplier	12	1	2	1.17	.389
Specialist contractor	16	1	2	1.50	.516

Company intranet

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	4	57.1	3	42.9
	Client	3	100	0	0
	Engineer/consultant	12	66.7	4	33.3
	Main contractor	2	40	3	60
	Manufacturer/supplier	7	58.3	5	41.7
	Specialist contractor	9	52.9	7	41.2
	Total	34	54.8	27	30.6

Descriptive Statistics : Company intranet

Company type	N	Minimum	Maximum	Mean	Std. Deviation
Architect	7	1	2	1.43	.535
Client	3	2	2	2	.000
Engineer/consultant	18	1	2	1.33	.485
Main contractor	5	2	1	2	.548
Manufacturer / supplier	12	1	2	1.42	.515
Specialist contractor	16	1	2	1.44	.512

In-house Specialist

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	6	85.7	1	14.3
	Client	1	33.3	2	66.7
	Engineer/consultant	10	55.6	8	44.4
	Main contractor	5	100	0	0
	Manufacturer/supplier	9	75	3	25
	Specialist contractor	11	64.7	5	29.4
	Total	42	67.7	19	30.6

Descriptive Statistics : In-house Specialist

Company type	N	Minimum	Maximum	Mean	Std. Deviation
Architect	7	1	2	1.14	.378
Client	3	1	2	1.67	.577
Engineer/consultant	18	1	2	1.44	.511
Main contractor	5	1	1	1	.000
Manufacturer/supplier	12	1	2	1.25	.452
Specialist contractor	16	1	2	1.31	.479
Total	62	1	2		

Project or section manager

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	3	42.9	4	51.7
	Client	0	0	3	100
	Engineer/consultant	6	33.3	12	66.7
	Main contractor	2	40	3	60
	Manufacturer/supplier	7	58.3	5	41.7
	Specialist contractor	8	50.0	8	50.0
	Total	31	50.0		

Descriptive Statistics : Project or section manager

Company type	N	Minimum	Maximum	Mean	Std. Deviation
Architect	7	1	2	1.57	.535
Client	3	2	2	2	.000
Engineer/consultant	18	1	2	1.67	.485
Main contractor	5	1	2	1.6	.548
Manufacturer/supplier	12	1	2	1.42	.515
Specialist contractor	16	1	2	1.50	.516

Line manager

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	4	57.1	3	0
	Client	2	66.7	1	42.9
	Engineer/consultant	18	100	0	0
	Main contractor	0	0	5	100
	Manufacturer/supplier	10	83.3	2	16.7
	Specialist contractor	8	47.1	8	47.1
	Total	26	41.9		

Descriptive Statistics :Line manager

Company type	N	Minimum	Maximum	Mean	Std. Deviation
Architect	7	1	2	1.43	.535
Client	3	1	2	1.33	.577
Engineer/consultant	18	1	1	1.00	.000
Main contractor	5	2	2	2	.000
Manufacturer/supplier	12	1	2	1.17	.389
Specialist contractor	16	1	2	1.50	.516

Descriptive Statistics : In-house resources

		Library:	Intranet:	In-house:	Project manager:	Line manager:
N	Valid	61	61	61	61	61
	Missing	1	1	1	1	1
Mean		1.31	1.44	1.31	1.49	1.57
Median		1.00	1.00	1.00	1.00	2.00
Mode		1	1	1	1	2
Std. Deviation		.467	.501	.467	.504	.499
Skewness		.835	.237	.835	.034	-.306
Std. Error of Skewness		.306	.306	.306	.306	.306
Kurtosis		-1.348	-2.011	-1.348	-2.068	-1.972
Std. Error of Kurtosis		.604	.604	.604	.604	.604
Minimum		1	1	1	1	1
Maximum		2	2	2	2	2

Distribution of in-house resources available to company

Company type		Company Library		Company Intranet		In house Specialist		Project manager		Line manager	
		f	%	f	%	f	%	f	%	f	%
Valid	Architect	4	57.1	4	57.1	6	85.7	3	42.9	4	57.1
	Client	2	66.7	3	100	1	33.3	0	0	2	66.7
	Engineer/consultant	18	100	12	66.7	10	55.6	6	33.3	18	100
	Main contractor	0	0	2	40	5	100	2	40	0	0
	Manufacturer/supplier	10	83.3	7	58.3	9	75	7	58.3	10	83.3
	Specialist contractor	8	47.1	9	52.9	11	64.7	8	50.0	8	47.1
	Total	42	67.7	34	54.8	42	67.7	31	50.0	26	41.9

(f – Frequency)

Question 18 If you have used an extranet or other IT platform to host project information what did it contain?

Drawings

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	7	100	0	0
	Client	2	66.6	1	33.3
	Engineer/consultant	11	61.1	7	38.9
	Main contractor	5	100	0	0
	Manufacturer/supplier	7	58.3	5	41.7
	Specialist contractor	11	64.7	4	23.5
	Total	43	67.2	17	26.6

Specification

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	5	71.4	2	28.6
	Client	1	33.3	2	66.7
	Engineer/consultant	11	61.1	7	38.9
	Main contractor	5	100	0	0
	Manufacturer/supplier	7	58.3	5	41.7
	Specialist contractor	11	64.7	4	23.5
	Total	40	62.5	20	31.3

Method statements

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	2	28.6	5	71.4
	Client	1	33.3	2	66.7
	Engineer/consultant	9	50	9	50
	Main contractor	3	60	2	40
	Manufacturer/supplier	10	83.3	2	16.7
	Specialist contractor	11	64.7	5	29.4
	Total	34	53.1	26	40.6

Technical standards

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	7	100	0	0
	Client	3	100	0	0
	Engineer/consultant	10	55.6	8	44.4
	Main contractor	5	100	0	0
	Manufacturer/supplier	7	58.3	5	41.7
	Specialist contractor	5	29.4	10	58.8
	Total	34	53.1	26	40.6

Supporting technical guidance

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	7	100	0	0
	Client	1	33.3	2	66.7
	Engineer/consultant	9	50	9	50
	Main contractor	3	60	2	40
	Manufacturer/supplier	9	52.9	6	35.3
	Specialist contractor	11	91.7	1	8.3
	Total	33	51.6	27	42.2

Health and safety information

	Company type	Frequency (**Yes**)	Percent	Frequency (**No**)	Percent
Valid	Architect	2	28.6	4	57.1
	Client	2	66.6	1	33.3
	Engineer/consultant	7	38.9	11	61.1
	Main contractor	3	60	2	40
	Manufacturer/supplier	10	83.3	2	16.7
	Specialist contractor	6	35.3	9	52.9
	Total	30	46.9	27	42.2

Descriptive Statistics:

		Drawings:	Specifications:	Method statement:	Standards:	Supporting information:	Health and safety:
N	Valid	60	60	60	60	60	57
	Missing	2	2	2	2	2	5
Mean		1.28	1.33	1.43	1.43	1.45	1.47
Median		1.00	1.00	1.00	1.00	1.00	1.00
Mode		1	1	1	1	1	1
Std. Deviation		.454	.475	.500	.500	.502	.504
Skewness		.986	.725	.276	.276	.206	.108
Std. Error of Skewness		.309	.309	.309	.309	.309	.316
Kurtosis		-1.063	-1.526	-1.991	-1.991	-2.026	-2.062
Std. Error of Kurtosis		.608	.608	.608	.608	.608	.623
Minimum		1	1	1	1	1	1
Maximum		2	2	2	2	2	2

Company type		Drawings:		Specifications:		Method statement:		Standards		Supporting information:		Health and safety:	
		f	%	f	%	f	%	f	%	f	%	f	%
Valid	Architect	7	100	5	71.4	2	28.6	7	100	7	100	2	28.6
	Client	2	66.6	1	33.3	1	33.3	3	100	1	33.3	2	66.6
	Engineer/consultant	11	61.1	11	61.1	9	50	10	55.6	9	50	7	38.9
	Main contractor	5	100	5	100	3	60	5	100	3	60	3	60
	Manufacturer/supplier	7	58.3	7	58.3	10	83.3	7	58.3	9	52.9	10	83.3
	Specialist contractor	11	64.7	11	64.7	11	64.7	5	29.4	11	91.7	6	35.3
	Total	43	67.2	40	62.5	34	53.1	34	53.1	33	51.6	30	46.9

(f – Frequency)

Appendix F A paper published in ICBEST 2007

THE PARALLEL INTEGRATION OF PARTICIPANTS AND PROCESSES IN THE CLADDING SUPPLY CHAIN

QIANG DU

Department of Architecture & Civil Engineering, University of Bath, Bath, BA2 7AY, UK,

Email: Q.Du@bath.ac.uk

ABSTRACT

Zooming in on the cladding supply chain, which is described by Ledbetter (2004) as a supply net, the participants can be seen as points linked by different procurement processes, and it is found that the relationships between players are complicated and are often fragmented. At the same time, the intertwining streams of information flow, product and service delivery and funding, frequently cause misunderstandings and conflicts among the participants in the network.

Inspired by the experience of some better performing industries and facilitated by rapidly developing information technology, the parties with different interests and processes from design to recycling of building envelopes could be parallelly integrated by clarified responsibilities and re-engineered standardizations respectively. On this basis, the people and processes can be integrated together by the interactive communication model, which is proposed in this paper. This communication model involves a third party, restructures the supply chain, and generates informed decision making and efficient negotiation frameworks. Thus seamless collaborative design, construction and maintenance in the whole lifecycle of building envelopes and 'win-win' objectives could be realized.

INTRODUCTION

The cladding industry is relatively independent and complex, having cotemporary features in a rapidly changing sector of the construction industry. The increasing complexity of technology and materials of building envelopes leads to continuously deepening specialisation in this sector, where more participants are involved and thus a multi-tier hierarchy of the cladding supply chain is formed.

Though relatively independent, cladding industry could not be discussed in an in-depth way without the context of construction. This paper would investigate some issues across construction industry if they commonly exist in the broader background. Actually, construction industry has been criticised for its low productivity, fragmentation and adversarial attitudes for several decades. It is even been doubted whether it deserves the term of ‘industry’ in *Why Is Construction So Backward* (Woudhuysen and Abley, 2004). The UK cladding sector is particularly noticed relatively weak and unable to take up most conventional technology based research results, and also fragmented, which reduce its capacity for technical innovative activities (Conaughton et al, 1993).

To improve the performance, supply chain management (SCM), already widely used in significantly better performing industries such as the automotive, information technology and retailing, has recently been introduced into the construction industry and become increasingly popular in both theoretical research and practical application.

It is clear that supply chain management is seen as an efficient tool to integrate the fragmented industry. Some new procurement strategies such as PFI, Design and Build and Prime Contracting are extensively adopted, especially by government clients, in new building procurement with the aim of integrating the supply chain through setting up long-term relationships between clients and main contractors. However, most of those approaches only work effectively in specific types of projects with strict boundaries. For instance, The *Building down Barriers* project (Holti et al., 2004), which proposes a single point responsibility procurement model, seems tailor-made for Ministry of Defence (MoD); PFI is trapped by spiralling bid cost and endless design changing, even if is only being practised in the public sector for projects such as hospitals and schools projects. One possible reason for this is that these attempts just try to justify the relationships in the existing supply chain rather than modify the supply chain's fundamental structure. A study carried out for the Department of the Environment (DoE) to guide its sponsorship of the cladding industry also revealed one of its main findings that "only changes in the industry's structure and interactions will change its capacity for innovative action" (Conaughton et al, 1993).

With thoughts of restructuring the supply chain, this paper zoom in on the cladding supply chain, which is described by Ledbetter (2003) as a supply net, to explore the possibility to achieve 'real' integration.

ANALYSIS

The concept of cladding supply chain consists of two categories of meanings: all necessary processes through design and construction, to maintenance, replacement and eventual demolition of the projects, and organisations involved in the processes, such as client/owner, designer, main contractor, subcontractor, and suppliers. It is not only a chain of construction businesses with business-to business relationships but also a network of multiple organisations and relationships, which includes the flow of information, the flow of materials, services or products, and the flow of fund between different participants (Xue et al, 2004). Figure 1 shows the information flow, product and service flow and funds flow streaming in a simplified supply network.

The complicated hierarchy of the supply chain is usually structured with multiple tiers of suppliers within the chain, where lower level suppliers provide materials to the next level of suppliers and so on through multiple levels of suppliers. There are also often several parallel or sequenced relationships between specialist sub-contractors or suppliers.

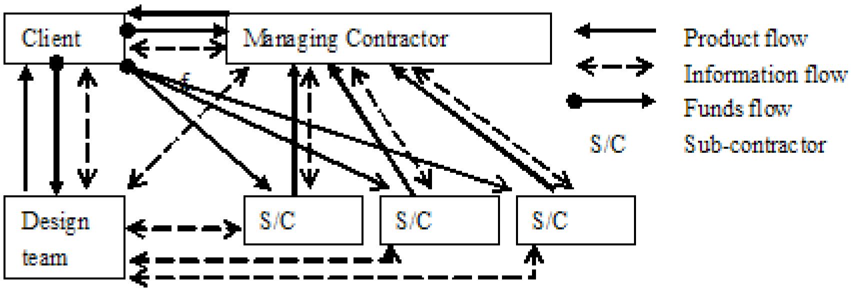

Figure 1 A simplified model of flows in the construction supply chain

On the other hand, it can be seen that communication network overlaps the product and service supply net on some routes such as between the client and the managing contractor, but not on others such as between the design team and sub-contractors. This finding implicates misunderstandings and conflicts are inevitable during the procurement processes, because that means products or services supply would sometimes be divorced from efficient communication. Financial problems, such as disputes over retentions, are essentially caused by similar reasons, but will not be discussed in this paper. This finding suggests the communication is the weakness of the industry, current supply chain structure, as commonly recognised by many practitioners and researchers (Dainty et al, 2005). However, the current supply chain structure seems cannot avoid the inherent flaw.

SEPARATION

Many recent researches suggest partnering strategy. This is a reasonable approach, but under the current supply chain structure, these long-term relationships are limited to few players with a narrow range of choices in practice

An initial idea in this paper is separating participants and processes from the complex net, analysing what the key factors are to achieve integration respectively, and integrating them parallelly. According to that, the two integrated sections can be combined together with radically restructured but suitable supply chain arrangements.

PARALLEL ANALYSIS AND INTEGRATION

In the supply chain, the participants are the people who create value and the processes are the activities which delivery value. For the flows of goods, service, information and finance, the participants make interfaces and the processes are the places where the interfaces exist, like the points and links respectively in a network. With supply chain management expertise, the points and links can be extracted separately to analyse and find ways to integrate respectively.

Integrating the participants

In the cladding supply chain, the participants could include client, design team/specifier, cladding consultant, main contractor, cladding management subcontractor, system designer, fabricator, installer, suppliers of glass, aluminium, gasket and sealant, and so on. Some organisations could play more than one role in the procurement.

The arrangements of participants are project-specific. However, a common thing what every player would like to achieve is value. Client wants to be delivered a functional facade within budget and time, designers would like to realise their innovative aspirations, and contractors desire profit, positive reputation and influence on the future market. It seems no big conflicts between their wishes, but fragmented relationships and adversarial attitudes exist in the real world. The issues often come from lack of trust and misunderstandings, which are the results of poor information exchange and communication.

The essentialities of integrating the participants is to enable them work in a collaborative way in a particular project and across projects under the help of optimised supply chain structure and communication approach, to achieve their own value. That might be the so-called 'win-win'.

Integrating the processes

The common cladding procurement processes could include inception, client brief, concept design/performance specification, project specific design, full specification, product drawings, manufacture of product parts, deliver to site, installation on site, handover, facilities manage/maintenance, demolition (Pavitt and Gibb, 2003).

The detailed sub-processes are also project-specific. However, the common target of the every single activity is delivering value. Value engineering provides a tool to assess and improve the value considering budget, time, quality, smoothness, and even altruism, but executing processes are often far away from best value. The issues are caused by weak decision-making mechanism, which can be improved by systematic knowledge management and better communication.

The processes might be unrepeatable for a specific client, designer or contractor, but the knowledge, experience, skill and innovation relationships gained from the processes should be managed for sharing in similar or related projects. Otherwise, there would be a potential enormous waste for the industry, like the current situation.

How can we combine the two sections?

In conclusion, to realise to parallel integration, the participants need to push the processes under collaborative working, and the processes should be executed under informed decision-makings. The 'collaborative working' here is a broader concept than 'partnering', which should extend the cooperation beyond partnerships and across projects; the decision-makings need serious knowledge management. All of the conditions require more efficient communication and more suitable working mechanism. Therefore, an interactive communication model with restructured supply chain is proposed.

SOLUTION

As described in the Analysis section, the finding concerning current flawed communication mechanism is the core but hidden causes for the broken cladding supply chain. The intertwining streams of information flow, delivery and funds flow, which link the participants with different interests, and structure the supply network, lead to misunderstandings and conflicts among the participants of the supply chain.

One solution is to make the communication network relatively independent of the supply chain. This initial idea could be developed and realised by the facilitation of information technology. The biggest challenge is modifying the traditional two-dimensional supply chain structure. In fact, traditional methods of cascading down the supply chain have some inherent defects which inhibit the rapid changes in technology, materials and complex multi-functional requirements that are needed. Communication practiced in the traditional supply chain structure may lead to:

- Simple corruption or loss of information
- Separation of the information from its original context
- Misuse of information

For example, windloading values have to be different for the structure, cladding components, glass and considerations of watertightness.

Therefore, a three-dimensional communication and supply model, supported by information technology and supply chain management expertise, is proposed. In this model, a 'third party' is incorporated as an 'information and communication hub', connecting with every original member in a supply chain (Figure 2). Information flow would therefore be integrated and facilitated.

Figure 2 shows the information hub will act as the pivotal part in the information exchange process. All information flows into the information hub and stays in an appropriate position where the members in the communication net can access certain areas. When any members need information, they just need ask for it from the information hub directly instead of other members who may only have unilateral information.

There are two senses of the term of "3D":

1) An information and communication hub is set up over the previous 2D partly overlapped supply and communication network, extending the structure of the whole supply network involving information flow, service flow and funds flow, to 3D space.

In the future, it could be extended to four-dimensional (4D) model when real long time multi-partnering leagues are set up, with the new space axis referring to 'time'.

2) The trinity integration of cash flow, information flow and goods/services flow from clients to manufacturers, with system engineering methods.
The reform of communication can make the decision-making process a real interactive process, making decision-making easier, quicker, and more accurate.

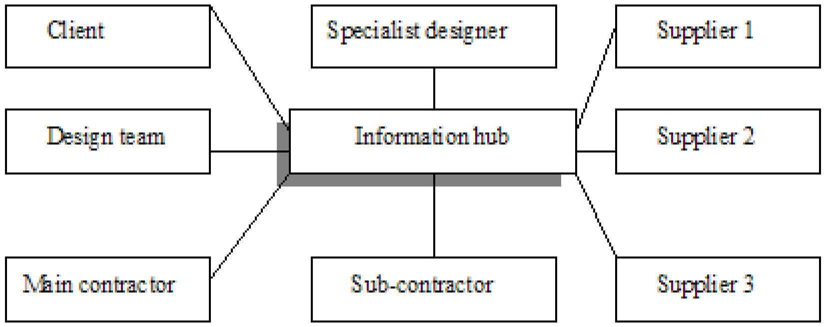

Figure 2 The independent communication net

THE REALISATION OF THE 3D MODEL IN PRACTICE

To realise the 3D communication model, the following concerns need to be identified:

The working mechanism of the 3D communication model

An 'information hub', the information interchange centre of 3D communication net, would have the ability to collect and process all necessary information from responsible parties, and provide the appropriate information to everybody involved in procurement, especially in the innovation process. It should be an interactive system, which permits individuals or organisations to contribute information and track latest decisions made by other parties in a project at any moment. When it is developed, this hub could offer active assistance in details, such as advice to installers on a work programme in the light of a weather forecast.

As we know, mainly because of the increased complexity of walls and the wide range of building solutions, performance specification has replaced prescriptive specification in many aspects. For example, in the case of facade design and construction, prescriptive specification requires in-depth knowledge of materials and detailing of curtain walling that is not always available to architectural specifiers. Performance specification allows architectural designers to specify at their level of knowledge the required performance of the wall and to pass detail responsibility to the specialist contractor. It is thought that performance specification can lead to good and economical design and construction by drawing on the specialist contractor skills, and it can also mitigate partly the conflict between architects and manufacturers.

However, the performance specification has to be translated to prescriptive specification in the end to aid manufacture and installation, mainly by specialist facade sub-contractors or cladding designers, and partly by other members of the procurement team. A point to be noted here is that the process of this “translation” is also an interactive process that all members take part in and contribute to. This requires that the proposed information hub must be an interactive communication centre to achieve the interactive specification.

To realize the general function listed above, an interactive database and an information manager or management group are necessary. In other words, an interactive information hub needs database software and people who support and run it.

The nature of a hub for the 3D communication model

In practise, some information may apply to more than one project, and some information is specific to a specific project. Thus, the information relevant to a project should be separated into two levels: intra-project information and extra-project information.

According to the two kinds of information, an information hub for the 3D communication net needs to be set up as a two-level hub, which includes intra-project level and extra-project level, Figure 3.

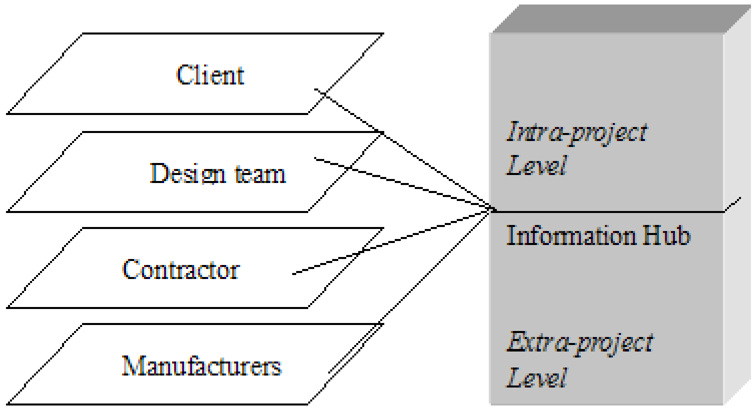

Figure 3 A two-level information hub

At the intra-project level, all participants in a particular project would submit the necessary information that they have and decisions that they have made, and "pick up" the appropriate information that they have access to. The information exchanged at this level includes project information details, such as the building design life, construction environments and component specific information.

At the extra-project level, general information would be provided by the information hub, including public information, semi-public information and subscripts, for instance, British Standard, Building Regulations and other specific standards or guidance. Participants in a project usually only receive appropriate information but do not need to contribute at this level.

Theoretical supports: the value of information sharing

In the 3D communication model, most communication and decision-making are based on a certain degree of information sharing offered by the information and communication hub. Therefore, it is important to ensure and measure the value of information sharing (IS).

There has been recent work related to the value of information sharing, coordination and collaborative decision making within a supply chain. There were opposite opinions since Lee and Whang (1999) firstly used quantitative method to analyse the types and applications of information sharing. The chaos continued until a comparative analysis on 12 current well-known models was made (Li *et al.*, 2005), and the conclusion of the review is that information sharing in the supply chain is valuable though the value and affecting factors are dependent on analytical assumptions, variable selections and analytical methods.

In fact, it would be meaningless simply to compare the numerical values in assumed mathematical models without practical framework. Although confident of the value produced by information sharing in the 3D communication model, the further work needs to be done to set up quantitative models based on practice, which might contribute to design more effective framework in details, especially when an IT supporting system is involved.

Technical support: information technology supporting system

In the framework of the 3D communication model, information technology (IT) plays an important role to realise real-time communication and management. The IT supporting system working in this framework would comprise hardware facilities and software packages, which would also realise mobile construction supply chain management.

Hardware Facilities

The hardware facilities would include:

1) Internet facilities, which are the channels for information exchange. Wireless technology would be appropriate on construction sites.
2) Server, based in the information and communication hub and in which the internet-based software and databases would be operated.
3) Personal facilities. Personal digital assistants (PDAs) could be more efficient for a hash environment like a construction site than personal computers or laptops. A bar code scanning system might provide increased speed and accuracy of data entry. Therefore, a bar-code-enabled PDA application (Tserng *et al.*, 2005) could be taken into account.

The hardware facilities are mature and sufficiently reliable to support the 3D communication model from the purely technical perspective, but the costs, IT training and other affecting factors need to be considered and balanced.

Software

The most important function of the software is to collect and classify all information from all aspects at different stages, and then distribute the appropriate information to appropriate parties in the building procurement project.

The software will have a manager interface and a user interface for the information manager and user respectively, which will enable an information manager or group to run more than one project simultaneously.

To avoid overloading participants and obscuring information, information would be categorised as:

- Core information, such as design life, that cuts across the whole project
- Shared information, such as harsh environments, that is requires by more than one subsequent decision maker
- Component specific information, such as colour of finishes, which is only required by a single supplier.

Different users will have different access rights to appropriate information. The responsibility for providing a particular piece of information will vary form project to project depending on the form of contract and the roles of the different parties.

A pilot project focusing on cladding supply chain have been explored, and a relevant software program, based on internet and SQL databases, has been developed, initially with the concepts illustrated above by Ledbetter (2004) and Qiang Du.

Who has the capability and responsibility to set up and run a hub?

Management of the information group could be undertaken by a professional organisation or an agent with relevant experience and management resources. The information manager may also have the responsibility of supervising the information programme, with the facility to email hub members automatically. To set up the hub, initial funding and facility support from Government, research organisations and industry would be necessary in the first stage. When the hub is established and has been proved, the hub could be promoted commercially.

In the case of the cladding sector, a well-known cladding industry based research organisation, such as Centre for Window and Cladding Technology (CWCT), which is an industry funded research organisation, with a membership of over 240 companies covering all parties in cladding procurement, and have enough experience and knowledge on cladding procurement management and IT, would have potential ability to set up and run the information hub.

BENEFITS, CHALLENGES AND FUTURE WORK

This model establishes a new communication network, a 'short circuit' above the above original supply net and without obstacles, restructuring the supply chain, facilitating integration of the participants under collaborating work in the supply chain and the processes under informed decision-making, and ultimately improving industry performance. The new supply chain structure with third party involved will also help to realise total quality management philosophy in industry wide by predictable continuous improvement (CI).

Theoretically, parties involved could work in a more collaborative way by clarified responsibilities and rights, no matter contractor-led, designer-led, or consultant-led; processed can be made more robust and fluent with contemporary IT facilities and supply chain management expertise. However, how can we make best use of the resources, is a question. On the other hand, a series of changes, including re-structure of the supply chain, participants re-oriented, IT training and usage in a relatively hash environment and traditional industry, third party incorporation, and every player will face revolutionary relationships and operation mechanism. How could we make the whole process smooth with minimised costs, and enable every participant work in real harmony? Many detailed tasks need further effort to work out.

CONCLUSIONS

It sounds contradictory to use separation to achieve integration, but it would be effective and correspond to the philosophy of the industry. This process can be seen as converting computer integrated manufacturing into an intelligent information system by combining CIM with concurrent engineering and knowledge management. The real long time and multi-partnering leagues within cladding sector would be formed. After being practically proved in the cladding sector, this strategy can be generalised across construction industry, and detailed tactic can be customised in different sectors according to various condition. A bigger picture is a four-dimensional model, which involves two senses: 4D space with a new axis referring to time; 4th party involved as the integrator of third parties in different levels and across several sectors. Further development could even involve Geographic Information System (GIS) to achieve full-scale relevant knowledge management.

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